

# Process-based land-surface modelling at ECMWF: interactive versus modular scheme development?

Gianpaolo Balsamo  
with support of several Colleagues at ECMWF

## ABSTRACT:

Recent land surface developments at ECMWF have led to an improved representation of some of the physical processes occurring at the land-atmosphere interface, verified against a variety of independent observational sources. In particular, a **MODIS-based leaf-area-index** climatology, which describes the seasonal evolution of vegetation, has replaced a fixed-in-time vegetation, and a revised bare-soil evaporation has introduced a larger extraction of superficial water in non-vegetated area. These two schemes revisions are shown to improve near-surface temperatures and soil moisture simulations. In an attempt of moving towards interactive ecosystems, a photosynthesis-based module has also been introduced in order to simulate **natural CO<sub>2</sub> emissions over land**. However, the land-carbon parameterization does not interact yet with the evapotranspiration formulation, and similarly, the vegetation seasonality representation does not interact with the momentum budget. These **"ad-hoc" separations of processes** have a practical advantage of **modularizing the model development** (particularly useful in community models) but may present some caveats of realism when representing naturally inter-dependent processes occurring in the Earth system. Examples from recent simulations will be used to illustrate this paradigm and the problems associated to full-coupling between processes.

# Outline

- **Introduction: model development in NWP & Climate**
- **Land surface evolution and current status**
- **Natural biosphere CO<sub>2</sub> uptake in NWP framework**
- **Ongoing land research**
- **Conclusions**

# Developments in Weather & Climate models

*The Earth surface model developments in NWP and Climate science differ in a number of aspects:*

**Main Drivers:** *Meteorological Users driven vs*

*Climate-Change-Science driven*

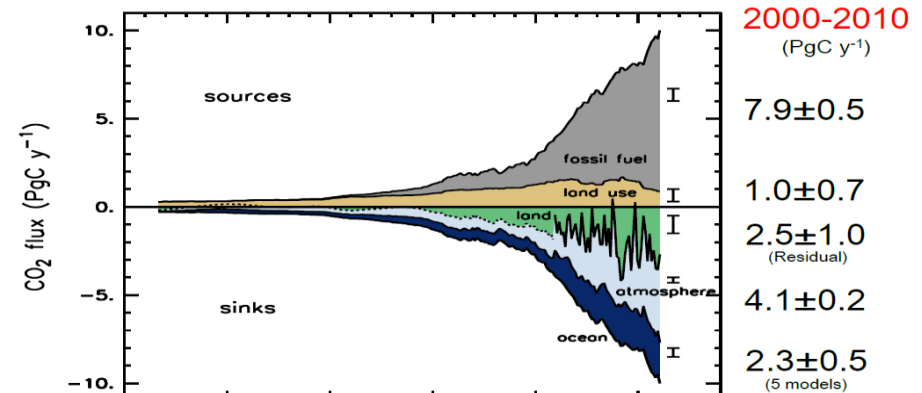
**Constraints:** *NWP systems have to be limited in complexity for timely daily production vs*

*Climate systems have to Include most of the relevant processes*

*(bio-physical but also bio-geo-chemical processes and complex feedbacks)*

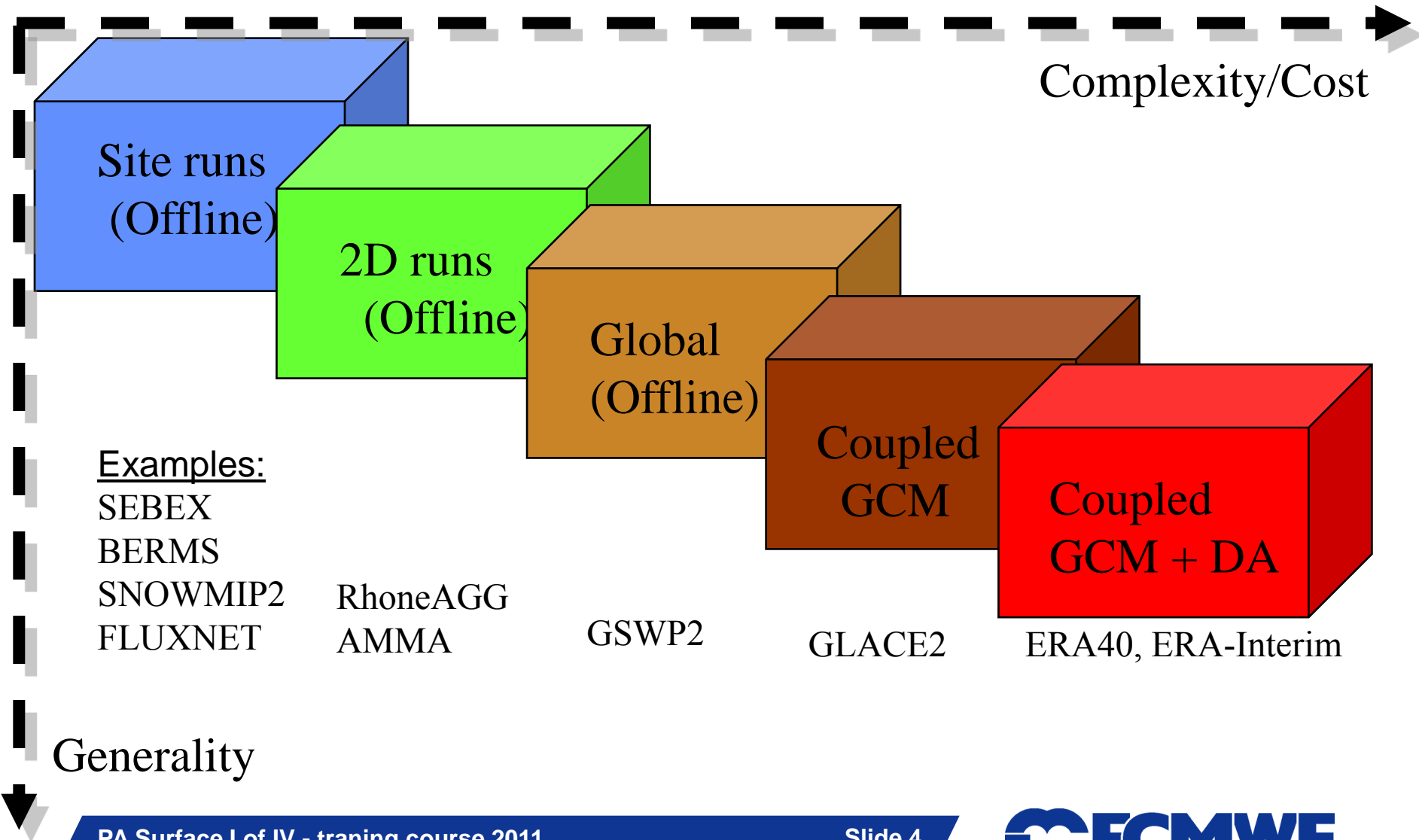
**Accuracy requirements:** *diurnal-to-synoptic timescale everywhere and with DA support vs*

*global annual trends in recent history*



Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS

# Strategy for land surface model development at ECMWF



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# Land Surface Model evolution

2000/06	2007/11	2009/03	2009/09	2010/11
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## ● TESSEL

Van den Hurk et al. (2000)  
Viterbo and Beljaars (1995),  
Viterbo et al (1999)

Up to 8 tiles (binary Land-Sea mask)

GLCC veg. (BATS-like)

ERA-40 and ERA-I scheme

## ● Hydrology-TESSEL

Balsamo et al. (2009)  
van den Hurk and  
Viterbo (2003)

Global Soil Texture (FAO)

New hydraulic properties

Variable Infiltration capacity &  
surface runoff revision

## ● NEW SNOW

Dutra et al. (2010)

Revised snow density

Liquid water reservoir

Revision of Albedo  
and sub-grid snow  
cover

## ● NEW LAI

Boussetta et al. (2011)

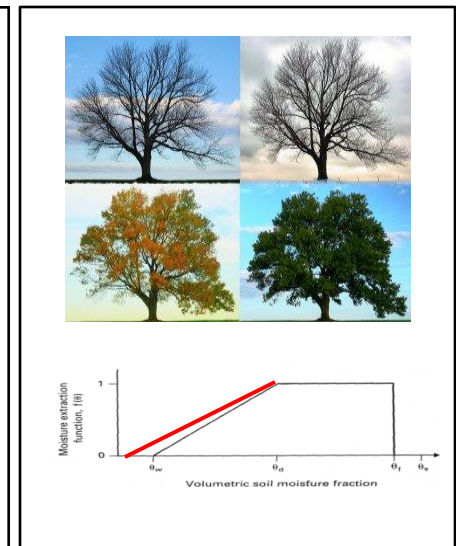
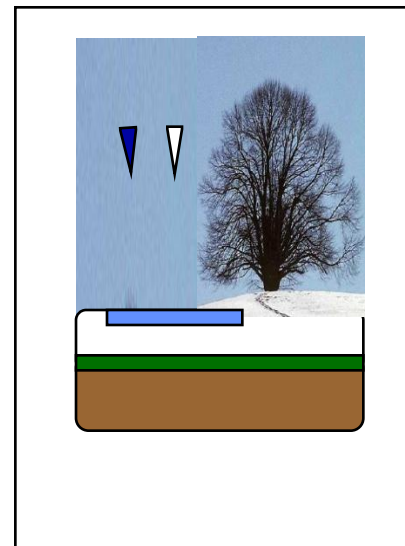
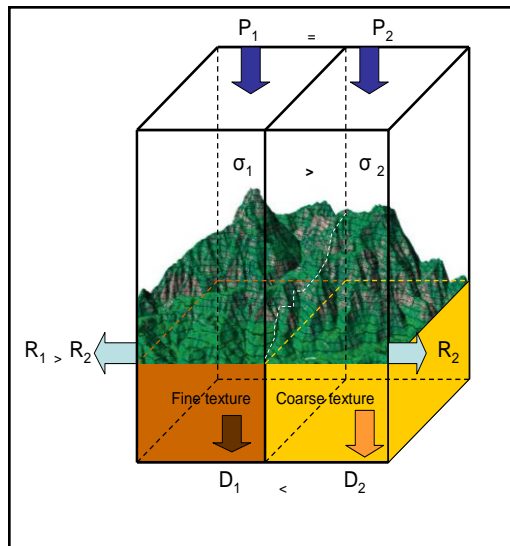
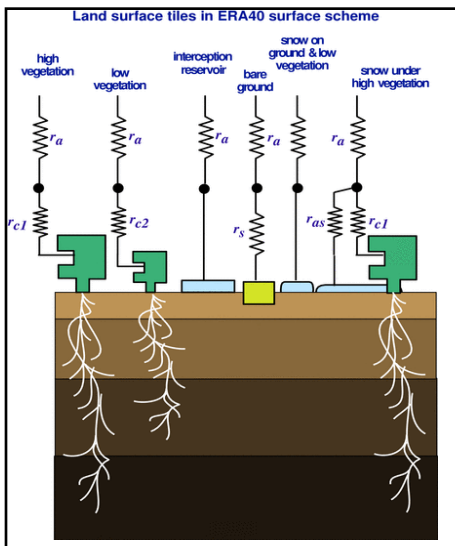
New satellite-based

Leaf-Area-Index

## ● SOIL Evaporation

Balsamo et al (2011) based on

Mahfouf Noilhan (1991)



# Land Data Assimilation system evolution

1999/07

2004/03

2010

- **OI screen level analysis**

Douville et al. (2000)

Mahfouf et al. (2000)

Soil moisture analysis based on  
Temperature and relative  
humidity analysis

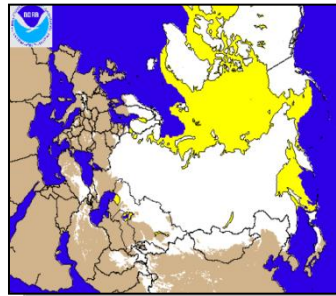


- **Revised snow analysis**

Drusch et al. (2004)

Cressman snow depth analysis using  
SYNOP data

Improved by using NOAA / NSEDIS  
Snow cover extend data



- **NEW EKF Soil Moisture analysis**

Drusch et al. (2009) De Rosnay et al.  
(2011)

Extended Kalman Filter developed for soil  
moisture analysis

- **NEW OI Snow analysis**

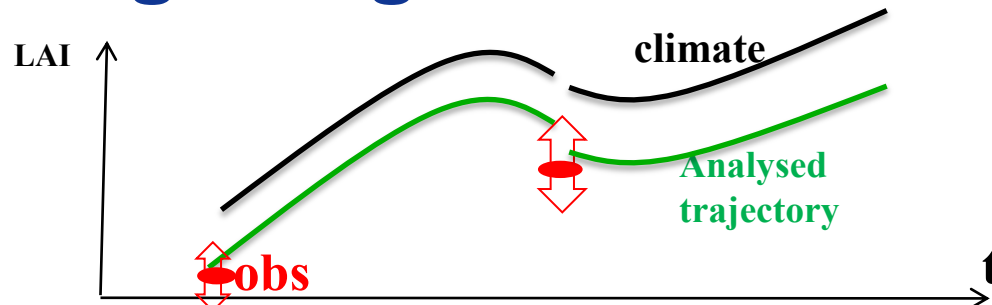


METOP-ASCAT



SMOS

## Integrating Leaf Area Index (in progress)



- **LAI univariate analysis**

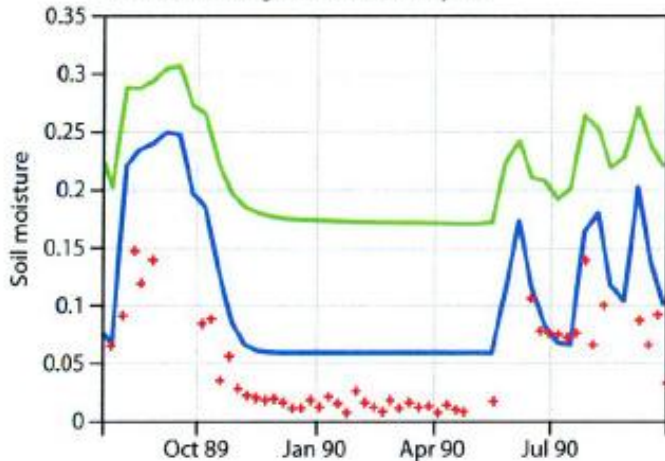
Exploratory study in Jarlan et al. (2009)

Developed within GEOLAND2 following  
Gu et al. (2006)

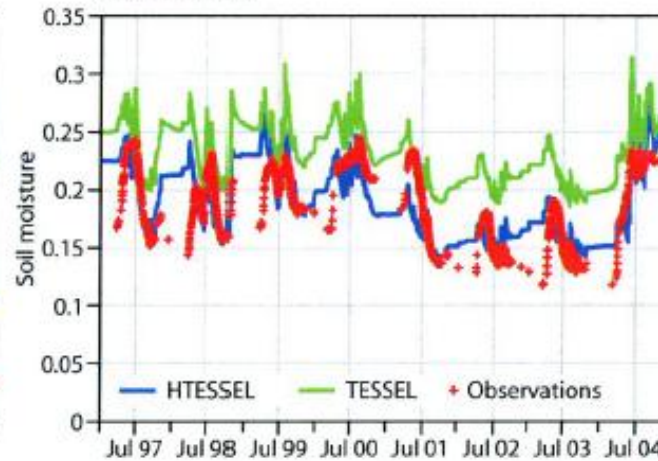
# Soil hydrology

(Balsamo et al. 2009, JHM)

**a** Savannah vegetation and sandy soil



**b** Boreal forest



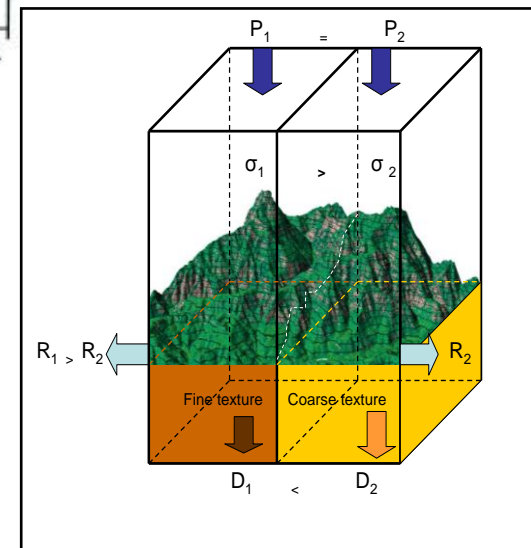
## ● Hydrology-**TESSEL**

Balsamo et al. (2009)  
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Global Soil Texture (FAO)

Van Genuchten  
hydraulic properties

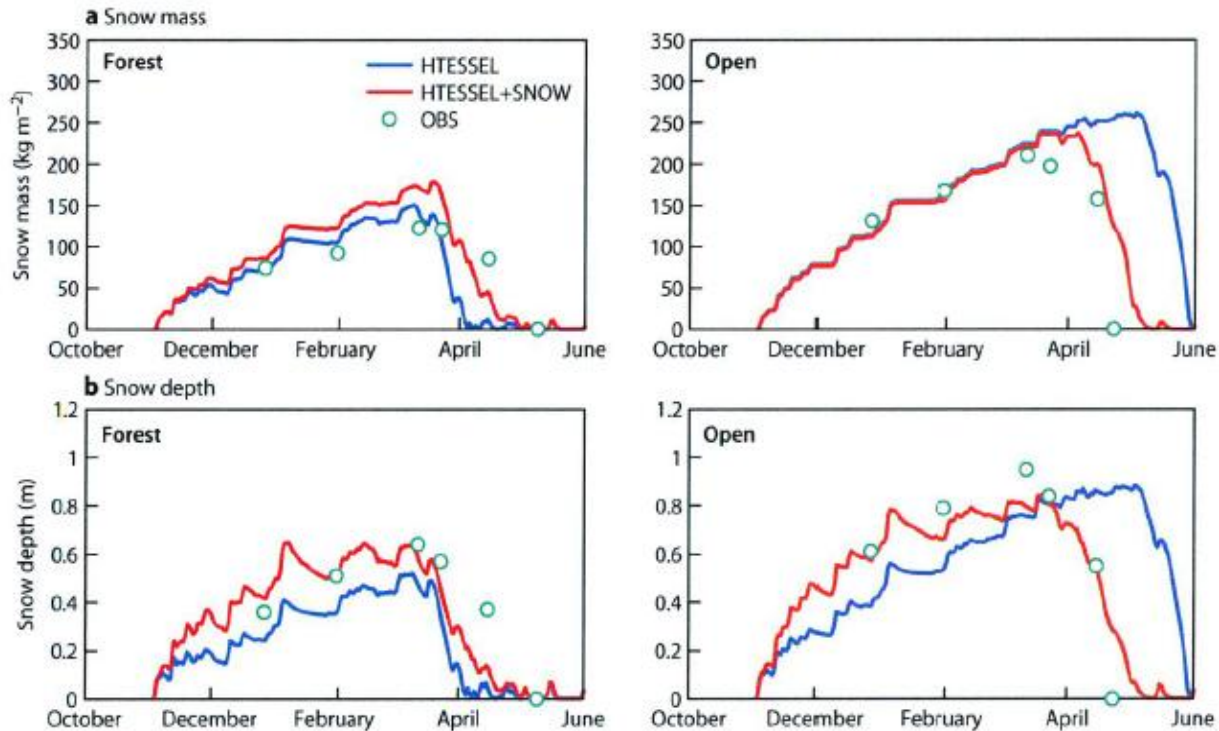
Variable Infiltration capacity &  
surface runoff revision





# New snow scheme

(Dutra et al. 2010, JHM)



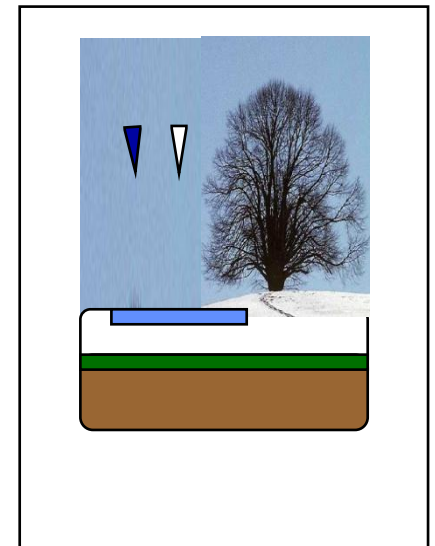
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Dutra et al. (2010)

Revised snow density

Liquid water reservoir

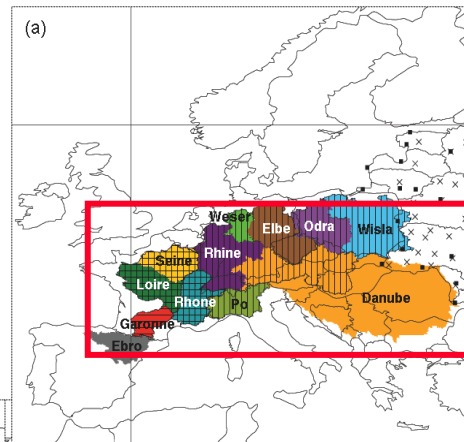
Revision of Albedo  
and sub-grid snow  
cover



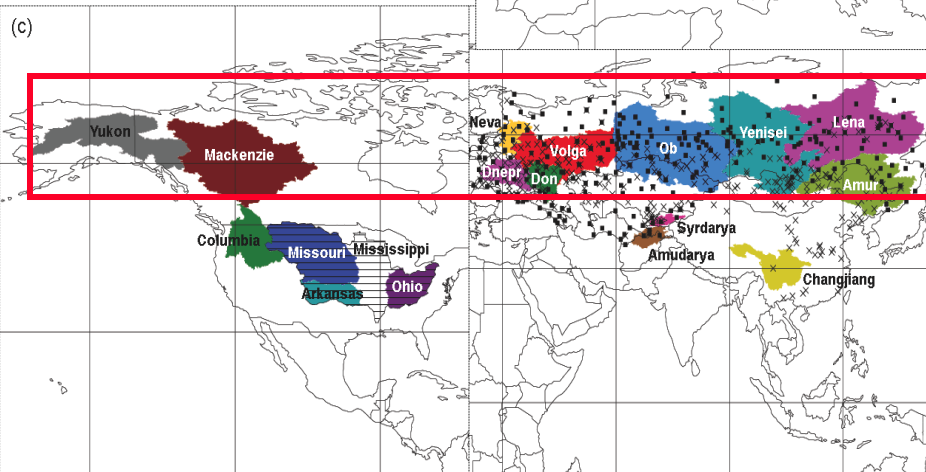
# Assessing impact on hydrological cycle

In Collaboration with M. Hirschi (ETH-Zurich)

ECMWF Newsletter No. 127 – Spring 2011



*In collaboration with  
ETH-Zurich, see also:  
Hirschi et al. 2006,  
J. Hydromet.,  
7(1), 39-60*



Parametrization scheme	Runoff RMSE (mm/day)	Observed area-weighted average runoff from GRDC (mm/day)
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Area-weighted average of snow-free basins ( $\sim 1,632,601 \text{ km}^2$ ):  
Northeast-Europe and Central-Europe

TESSEL	0.28	0.76
HTESSEL	0.17	

Area-weighted average of snow basins ( $\sim 12,334,161 \text{ km}^2$ ):  
Yukon, Podka., Lena, Tom, Ob, Yenisei, Mackenzie, Volga, Irtysh and Neva

HTESSEL	0.75	1.96
HTESSEL+SNOW	0.51	

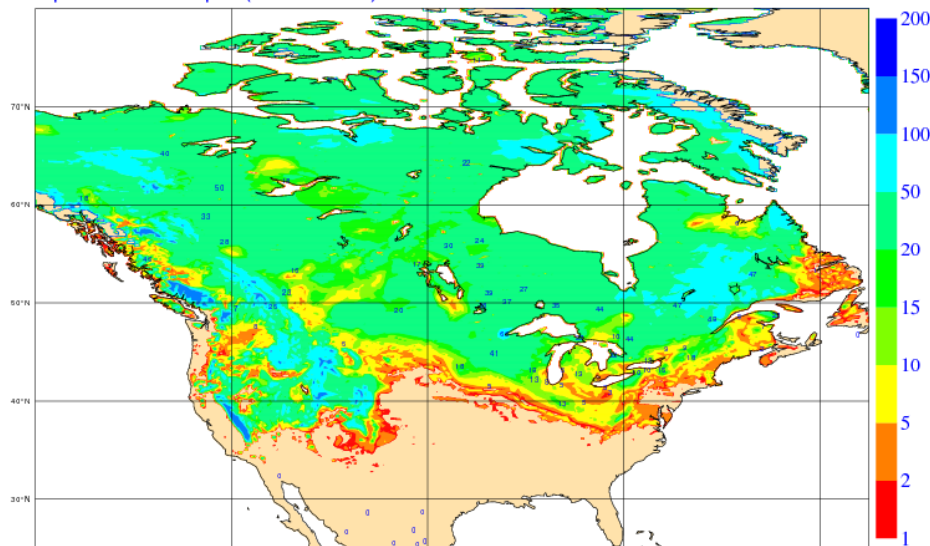
**Table 1** Runoff root-mean-square error (RMSE) for GSWP2 from global offline simulations (1986–1995) verified with GRDC observations on snow-free basins for TESSEL, HTESSEL, and snow-dominated basins for HTESSEL, HTESSEL+SNOW.

Using an equal forcing (this time based on ERA40GPCP corrected forcing) TESSEL and the new land surface model version currently operational can be evaluated against river discharges of main Northern Hemisphere river at monthly timescales (no routing). New activities with river-routing schemes can assess hydrological impact on daily timescale (Pappenberger et al.)

# Snow verification US (Winter 2010-2011)

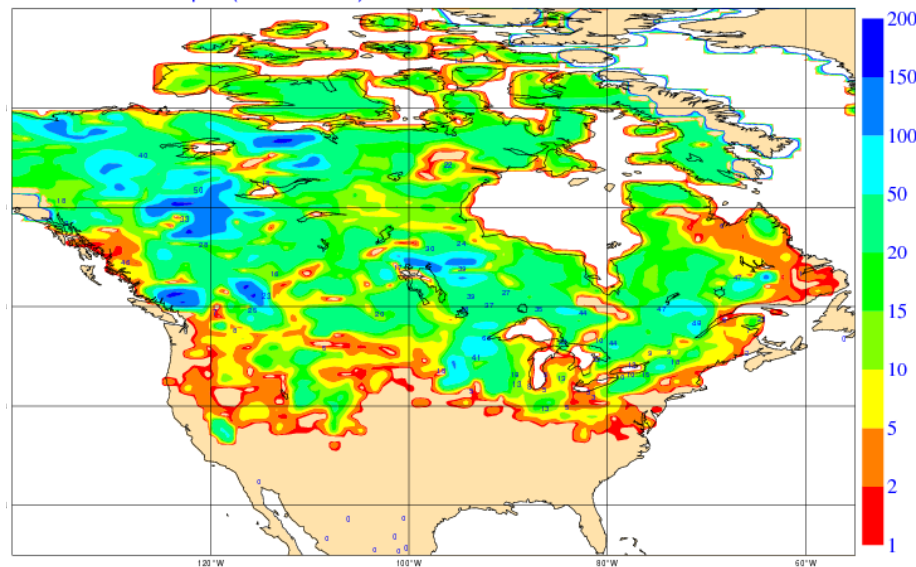
## Operational-suite

Oper SNOW Depth (cm of snow) vs. SYNOP observations 20101223 at 6UTC

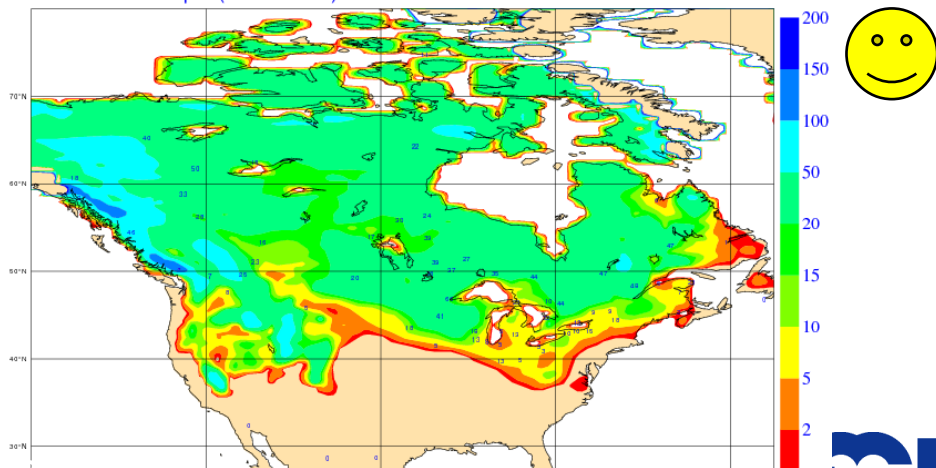


## ERA-Interim

ERA-I SNOW Depth (cm of snow) vs. SYNOP observations 20101223 at 6UTC



OSM SNOW Depth (cm of snow) vs. SYNOP observations 20101223 at 6UTC



New  
Land  
EI-forced

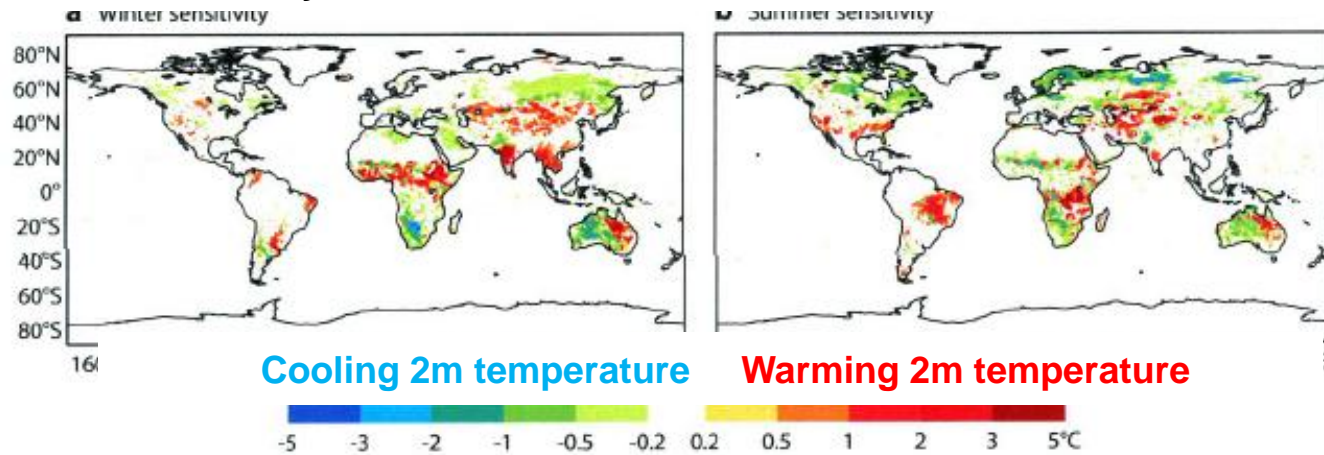
NASA GSFC 2011/2012

DECMWE

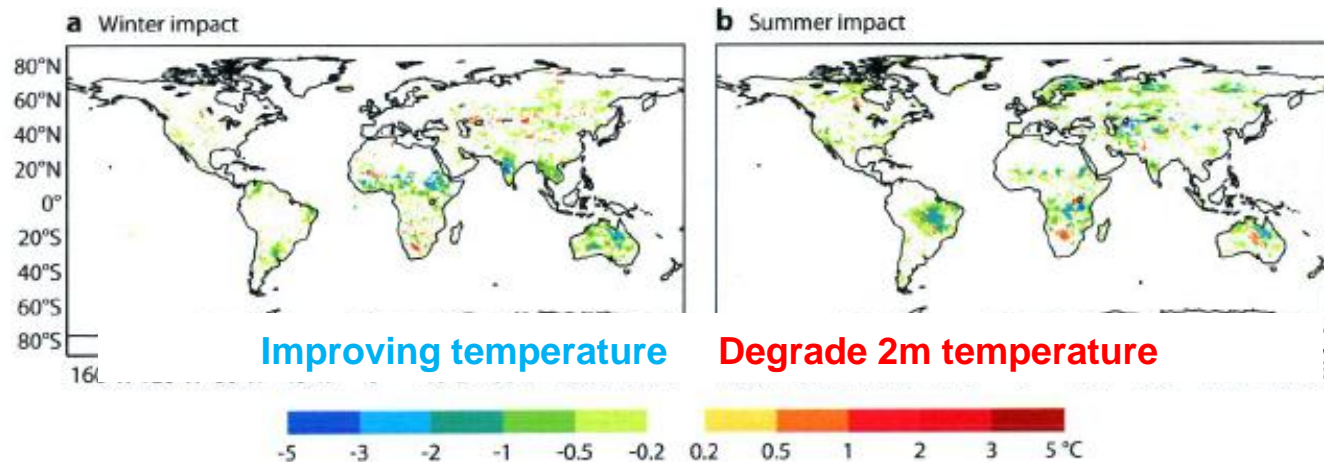
Operational snow analysis (de Rosnay et al., 2011) has been greatly improved and there is consistency to the OSM-EI output. EI is also improved w.r.t. 2009 for geolocation of NESDIS snow data. Cressman is shown to be linked to Pacman snow feature

# Forecasts sensitivity and impact

## Forecast sensitivity



## Forecast Impact

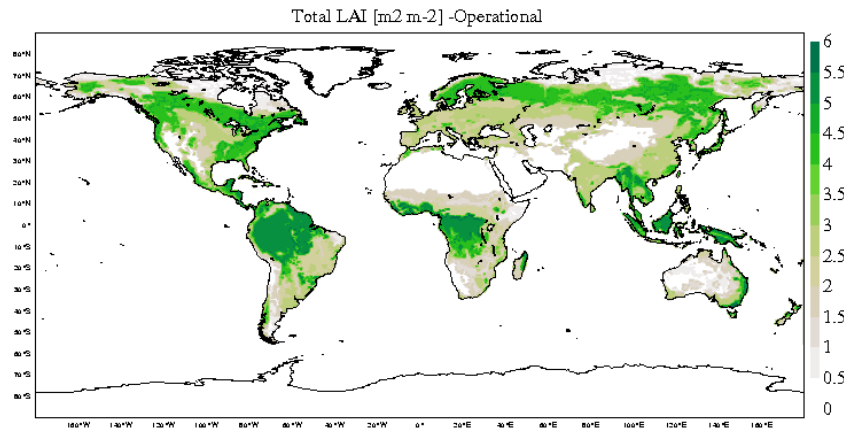


The revised soil/snow scheme introduce additive improvements respectively in summer/winter seasons forecasts of 2m temperatures



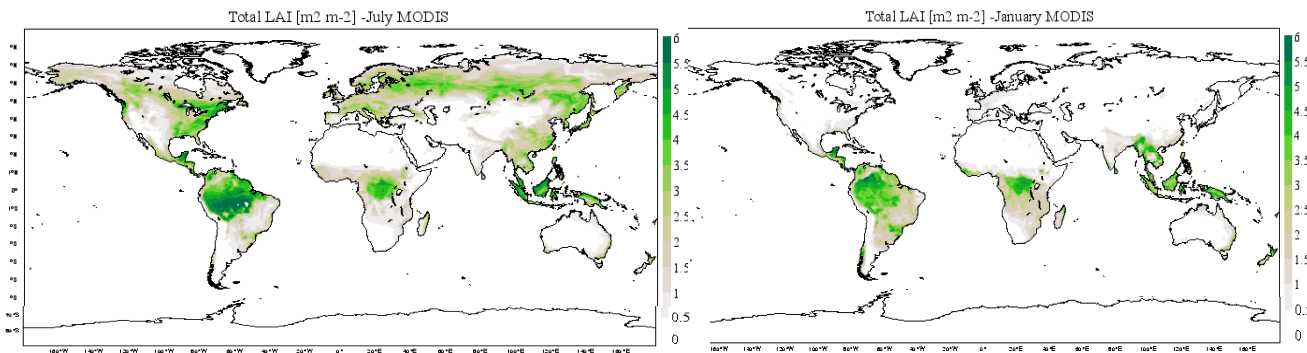
# New vegetation seasonality

(Boussetta et al. 2011, IJRS)



Previous LAI (van den Hurk et al. 2000, ECMWF TM295)

MODIS LAI (c5) Myneni et al., 2002, Jarlan et al. 2009

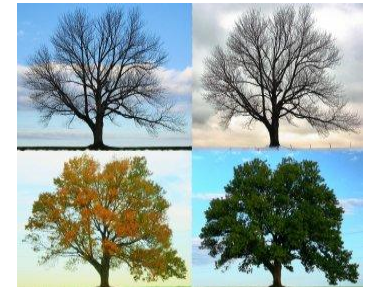


## ● NEW LAI

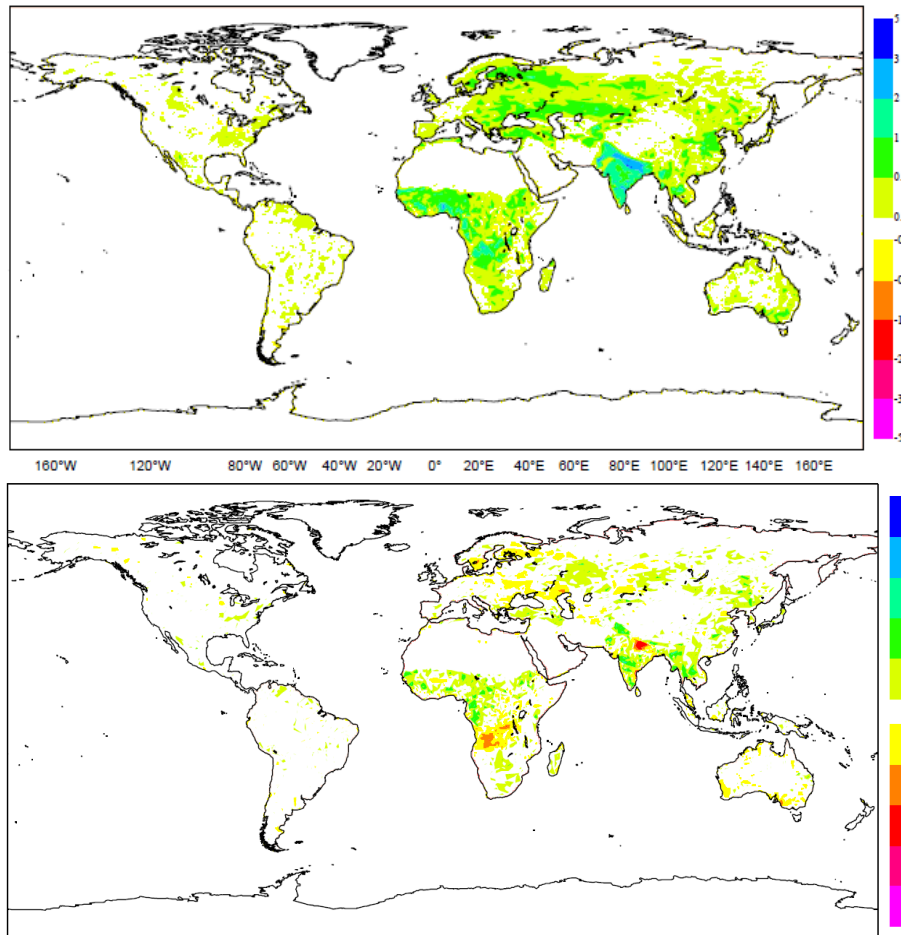
Boussetta et al. (2011)

New satellite-based

Leaf-Area-Index

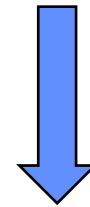


# Impact of the usage of the MODIS based monthly LAI climatology on the 2m Temperature



Sensitivity  
(warming)

$$Sensitivity(T) = T_{MLAI} - T_{ctl}$$



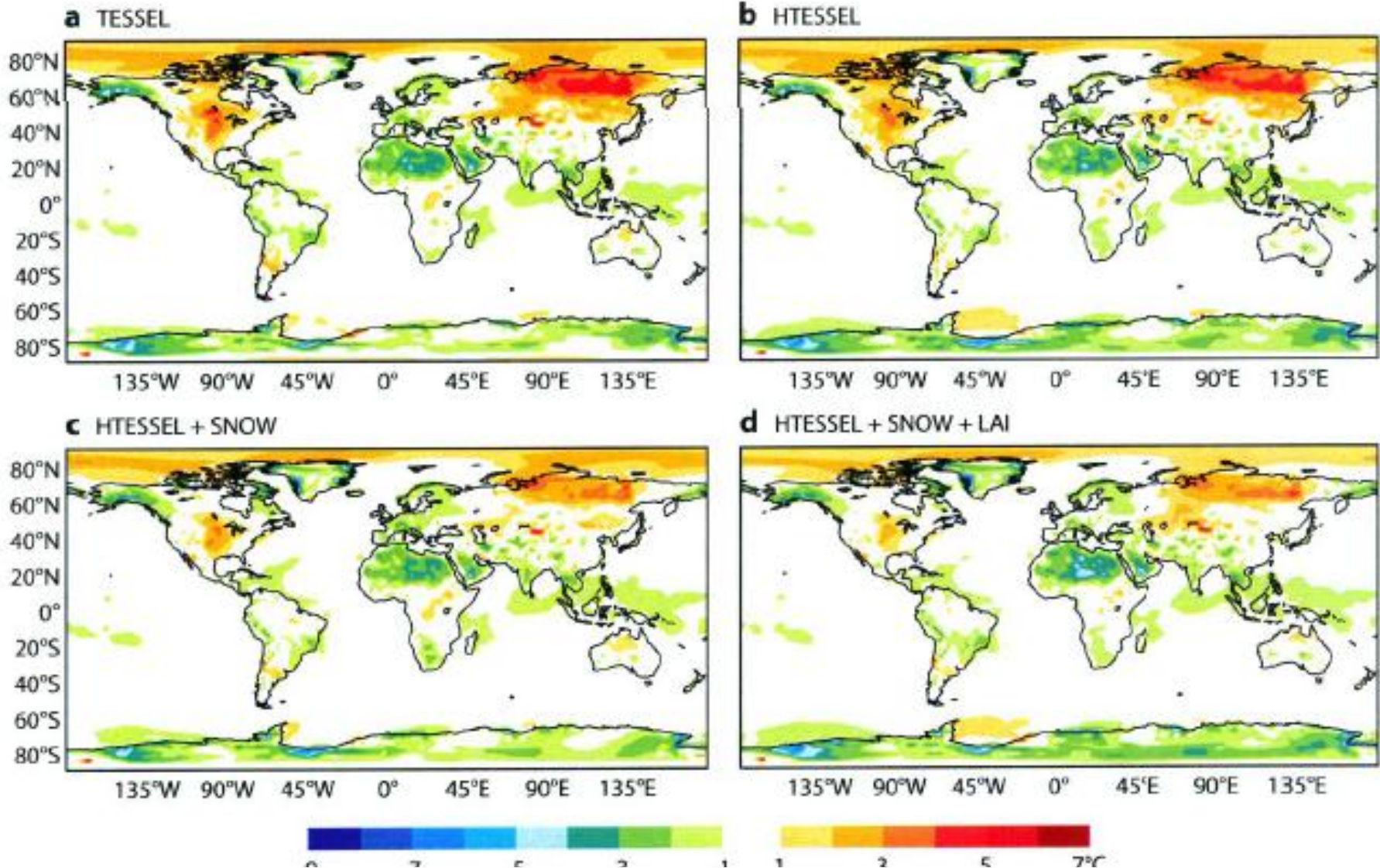
Impact  
(error reduction)

$$Impact(T) = |T_{ctl} - T_{an}| - |T_{MLAI} - T_{an}|$$

Results from forecast experiments using MODIS LAI relative to the fixed LAI case for MAM at FC+36 (valid 12UTC), 2m temperature [K]

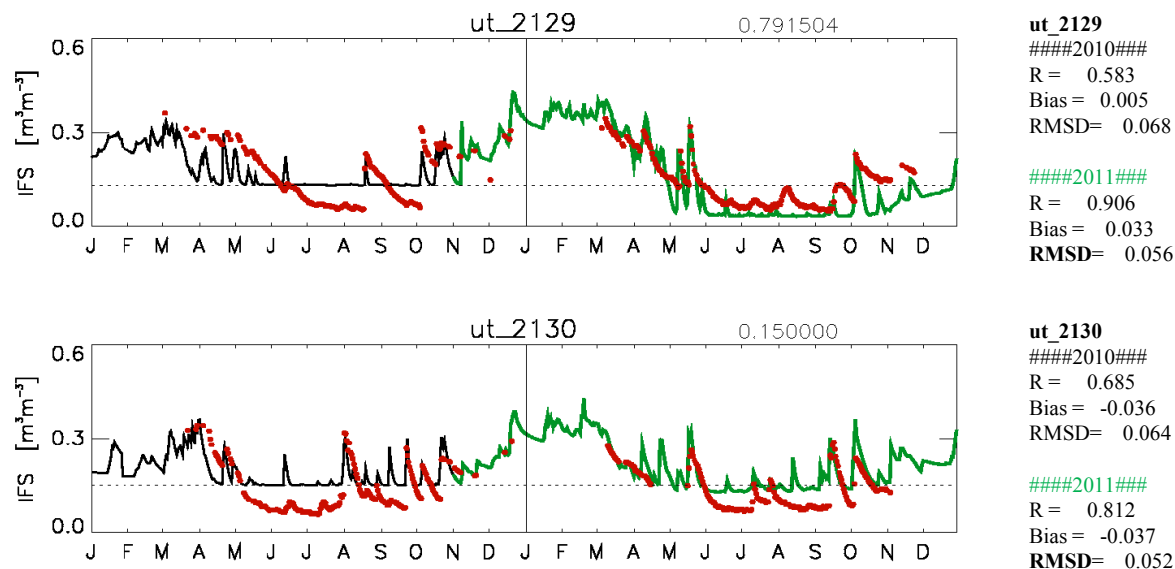
# Climate simulations: the impact of land

Hindcasts, 4-member 13-month temperature difference



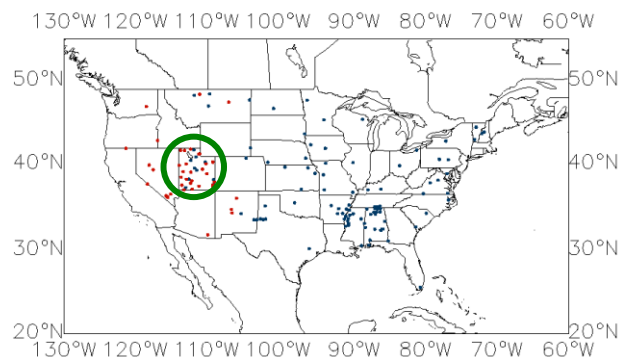
# New bare soil evaporation

Albergel et al. 2012, in preparation



The introduction of bare ground evaporation revision (green-line) is quite effective in reducing the soil moisture below the wilting point in non-vegetated area (upper panel of figure above, at 79% bare ground, SCAN site in Utah).

$$R_c = R_{\text{soil}} f_2(w_1)$$

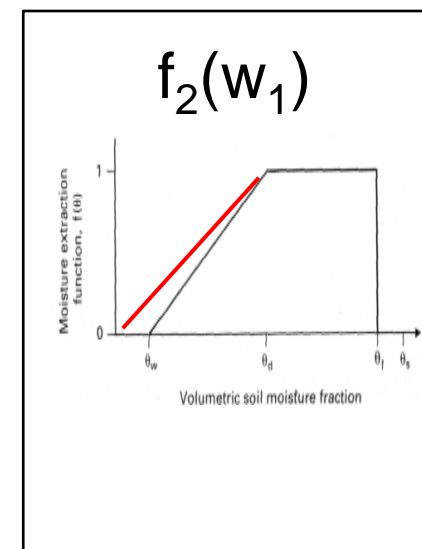


## SOIL Evaporation

Balsamo et al. (2011)

based on

Mahfouf and Noilhan (1991)



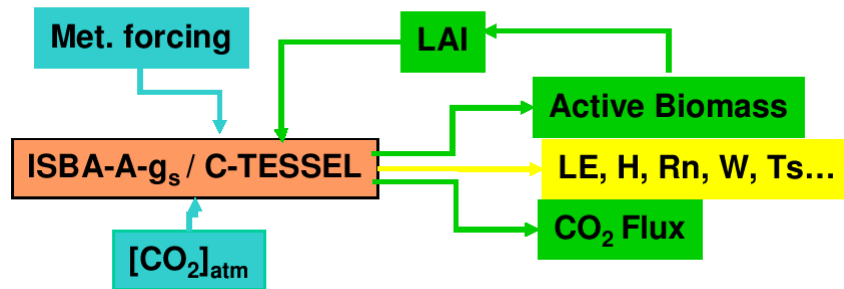


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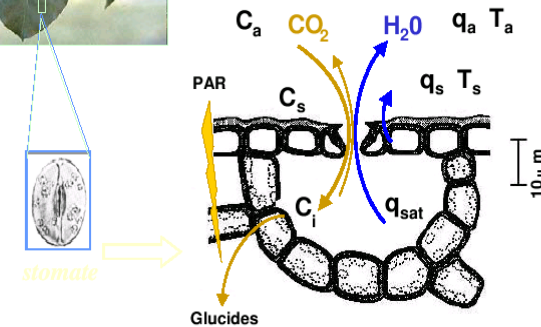
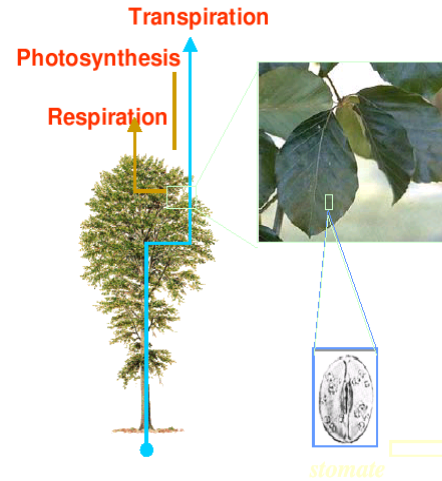
# Land carbon/photosynthesis-based parameterisation (CTESSEL)

(Boussetta et al. 2012, in preparation)



$$A_n = \frac{\alpha}{r_{cc}} (C_s - C_i)$$

$$E = \frac{\beta}{r_c + r_a} (q_a - q_{sat}), r_c = f(r_{cc})$$



The stomatal aperture controls the ratio:

**Photosynthesis/Transpiration**

according to the environment conditions

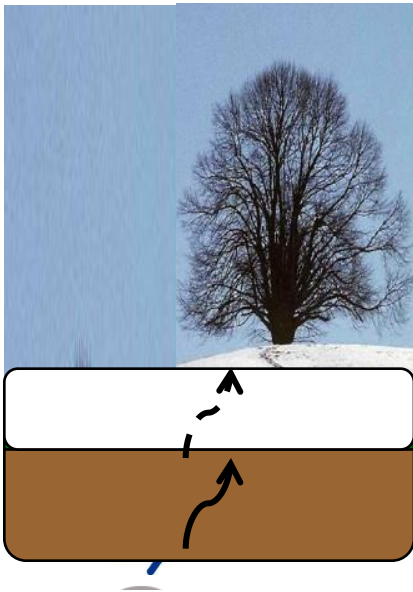
Light, temperature, air humidity  
soil moisture, atmospheric [CO<sub>2</sub>]

CTESSEL combines HTESSEL (Balsamo et al. 2009) with the A-gs model used within the ISBA-Ags (Calvet et al. 1998) and developed by Jacobs et al. (1996);

- ➔ Account for the effect of CO<sub>2</sub> concentration and the interactions between all environment factors on the stomatal aperture.
- ➔ Replaces the Jarvis-type stomata conductance by a **photosynthesis dependant-type stomata conductance** (Jacobs et al. 1996)
- ➔ The model can account for the vegetation response to the radiation at the surface, temperature, soil moisture, temp stress
- ➔ Vegetation Assimilation of CO<sub>2</sub> can be used to drive a vegetation growth module to simulate LAI
- ➔ The Ecosystem Respiration is parameterized as a function of soil temperature, and soil moisture and biome type via a reference respiration parameter

# Soil Respiration improvement for winter season (1)

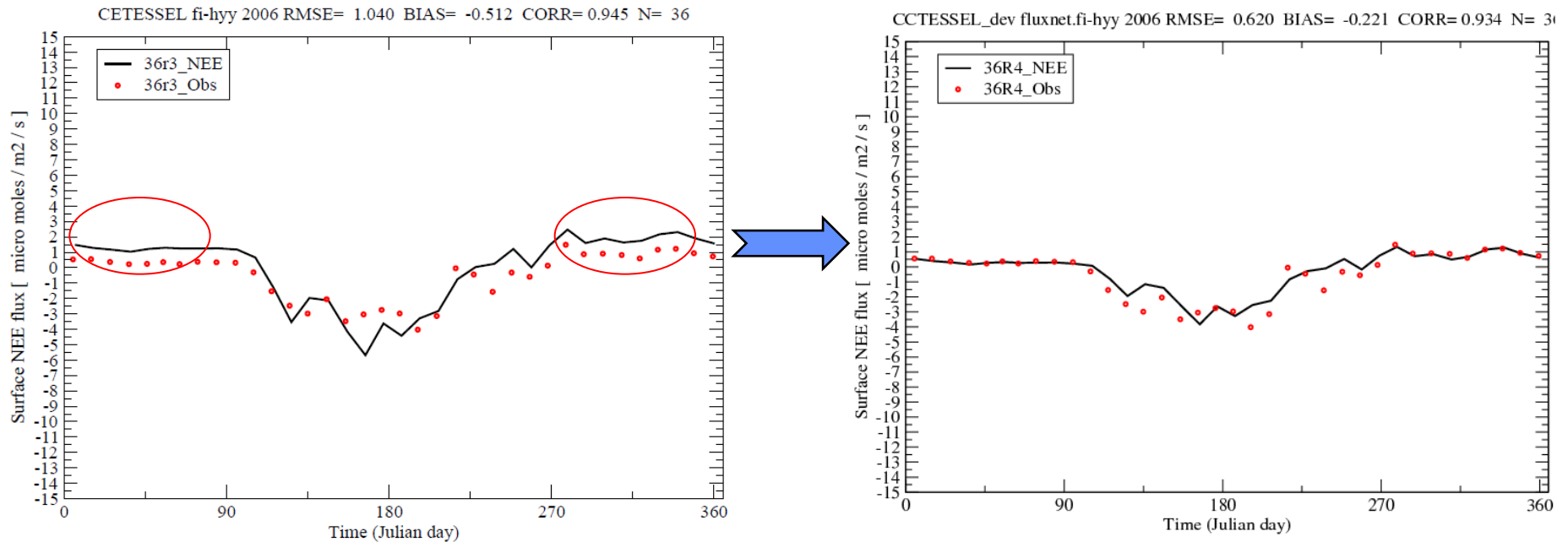
$$R_{soil} = R_0 Q_{10}^{(0.1(T_{soil}-25))} f_{sm} \quad \Rightarrow \quad R_{soil} = R_0 e^{-\alpha \cdot Z_{snow}} Q_{10}^{(0.1(T_{soil}-25))} f_{sm}$$



Including a snow attenuation effect on the soil CO2 emission

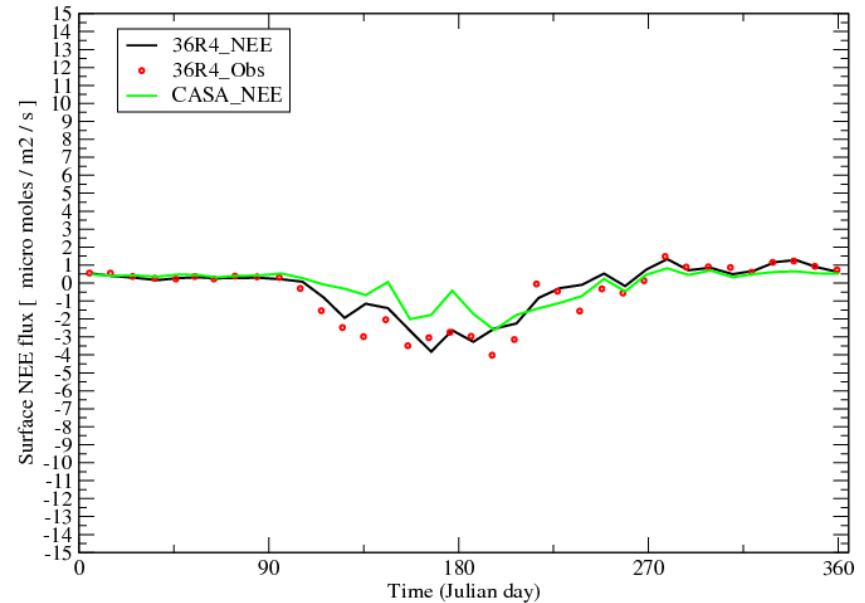
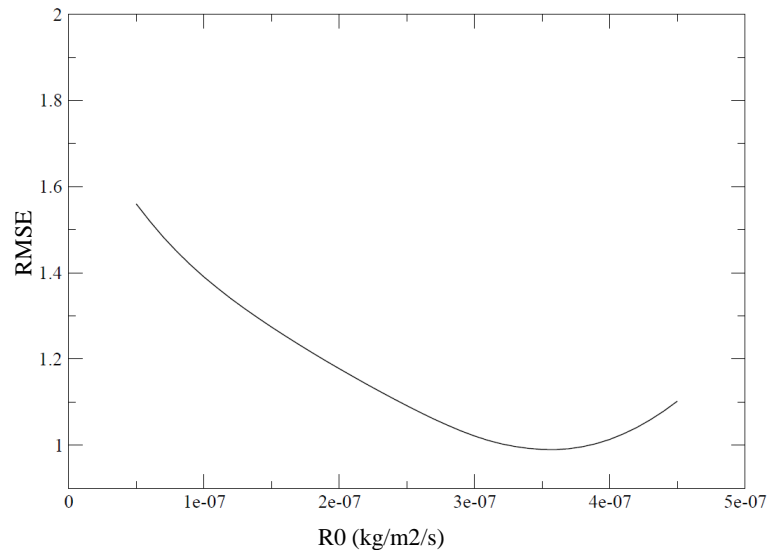
Preliminary test in atmospheric coupled MACC model including CO2 contributed to identify a relevant process to be represented in order to adjust the contribution from the surface

# Soil Respiration improvement for winter season (2)



Example of NEE (micro moles /m<sup>2</sup>/s) predicted over the site Fi-Hyy taking the cold process into account (right) and previous simulation (left) by CTESSEL (black line) and observed (red dots)

# Optimization of CTESSEL parameters by vegetation types

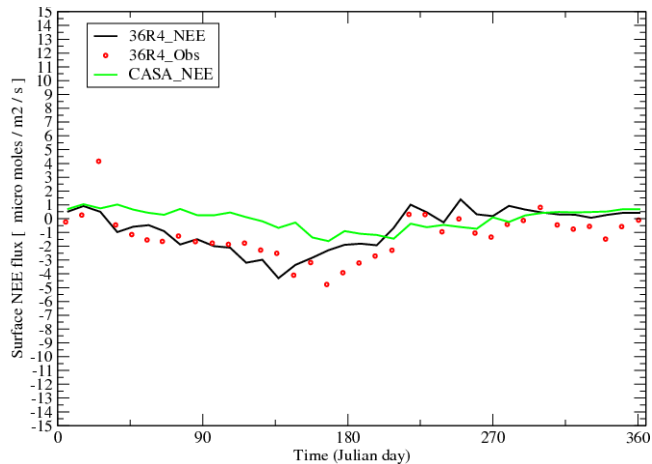


Example of R0 optimization for the Evergreen Needleleaf Forest

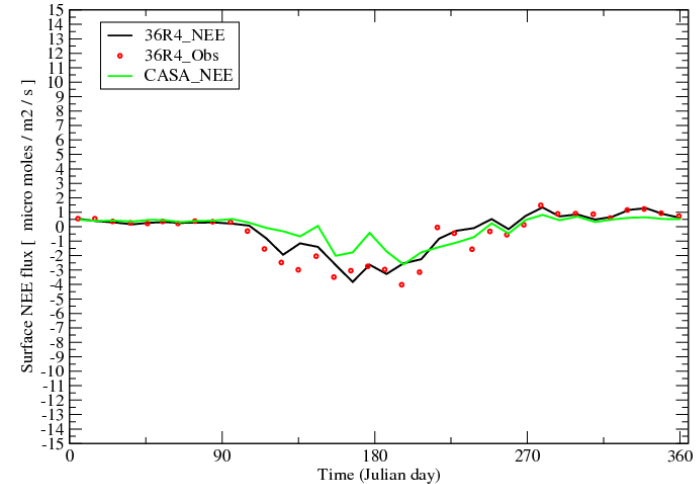
Example of NEE (micro moles /m<sup>2</sup>/s) predicted over the site Fi-Hyy by CTESSEL (black line) and CASA-GFED3 (green-line)

Scheme	GPP rmse	GPP bias	GPP corr	NEE rmse	NEE bias	NEE corr	Reco rmse	Reco bias	Reco corr
CTESSEL	7.936	-6.224	0.743	3.736	-1.656	0.536	5.422	4.625	0.724
CASA	-	-	-	1.872	0.739	0.297	-	-	-

# Improved Skill in simulating Net Ecosystem Exchange (1)

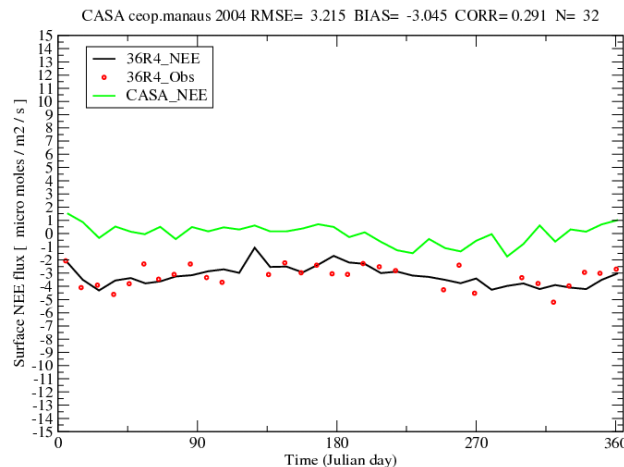


**NEE for  
Two European sites**



Example of NEE (micro moles /m<sup>2</sup>/s) predicted over the site **Fr-LBr**(left) and **Fi-Hyy** (right) by **CTESSEL** (black line) and **CASA-GFED3** (green-line)

**NEE for Amazon  
site (Manaus)**

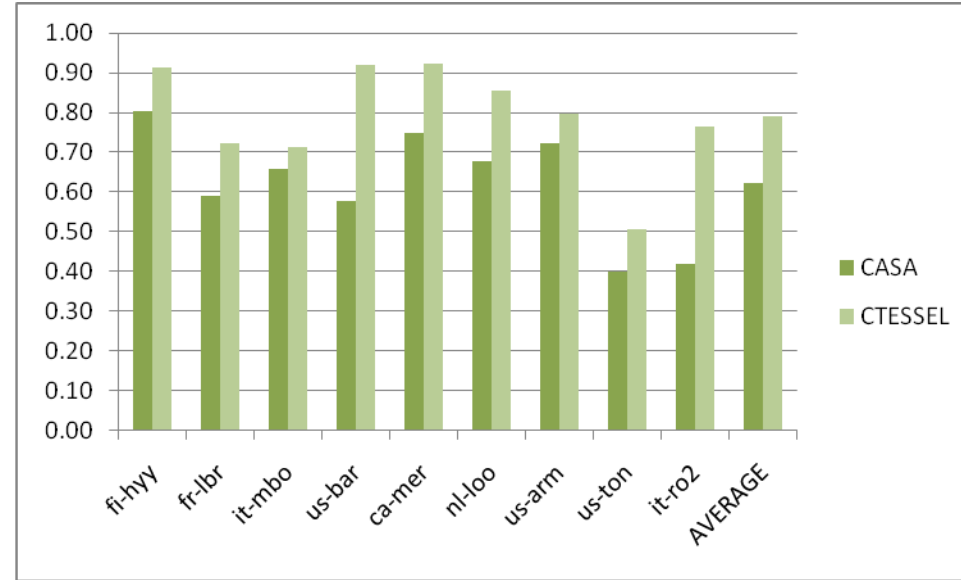


Example of NEE (micro moles /m<sup>2</sup>/s) predicted over the Manaus tropical site by **CTESSEL** (black line) and **CASA-GFED3** (green-line)

# Improved Skill in simulating Net Ecosystem Exchange (2)

Country	Flux-tower Site	Vegetation Type
Finland	fi-hyy	Evergreen Needleleaf Forest
France	fr-lbr	Evergreen Needleleaf Forest
Italy	it-mbo	Grassland
USA	us-bar	Deciduous Broadleaf Forest
Canada	ca-mer	Deciduous Broadleaf Forest
Netherland	nl-loo	Evergreen Needleleaf Forest
USA	us-arm	Crops
USA	us-ton	Woody Savannas
Italy	it-ro2	Deciduous Broadleaf Forest

List of sites used for the verification of NEE fluxes of the updated CTESSEL scheme (model assigned physiography)

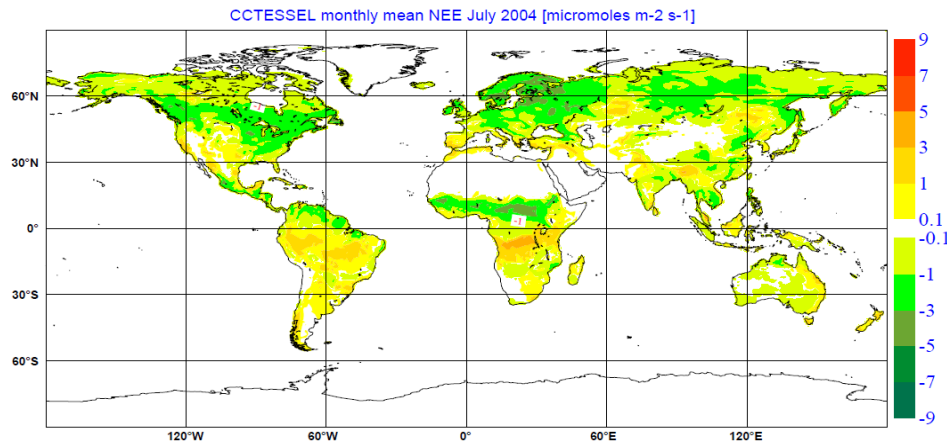


Correlation of modelled and observed NEE for CASA-GFED3 and for CTESSEL over 9 sites with different dominant biomes

➔ After the redefinition of vegetation dependent parameters in CTESSEL and the Inclusion of snow and cold temperature attenuation effects on land carbon emission, => CTESSEL is outperforming CASA-GFED3 on most of the northern-hemisphere and tropical stations with the 1-D offline simulation.

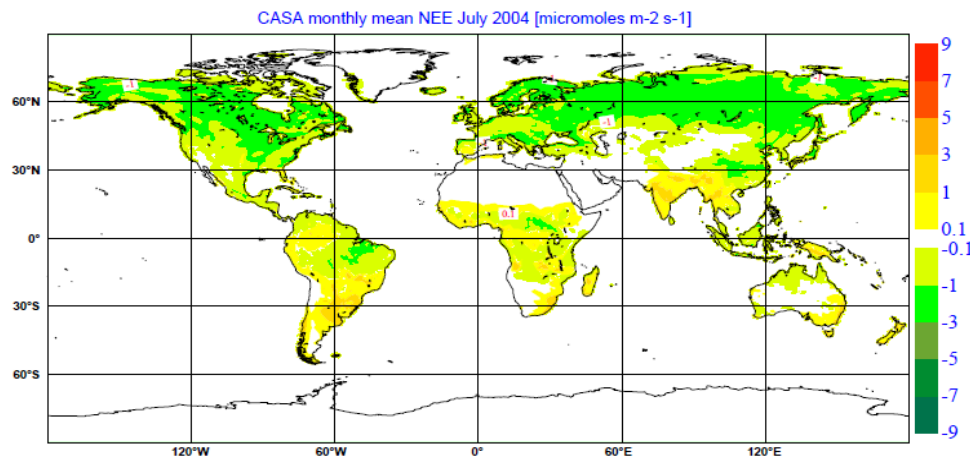
# Comparing with State-of-the-art global natural carbon dioxide

CTESSEL



- similar patterns over the northern hemisphere
- CTESSEL has more spatial variability than CASA due to its link with meteorological forcing

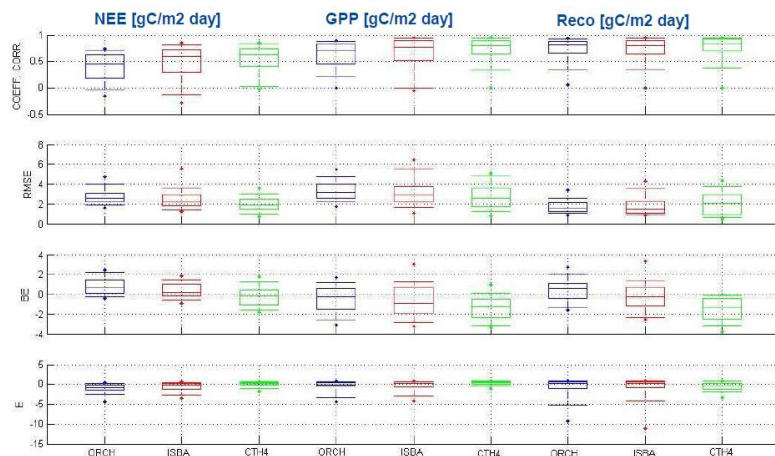
CASA





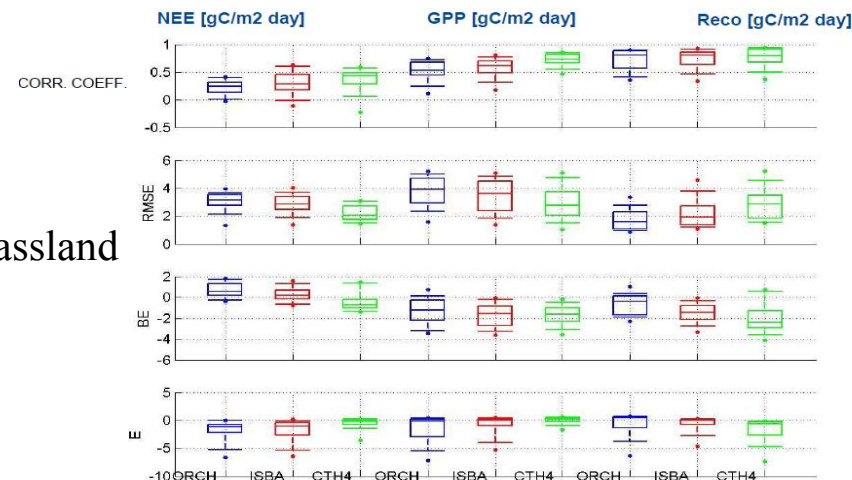
# Independent Validation of CTESSEL

Courtesy from M. Balzarolo, (UNITUS, Italy)

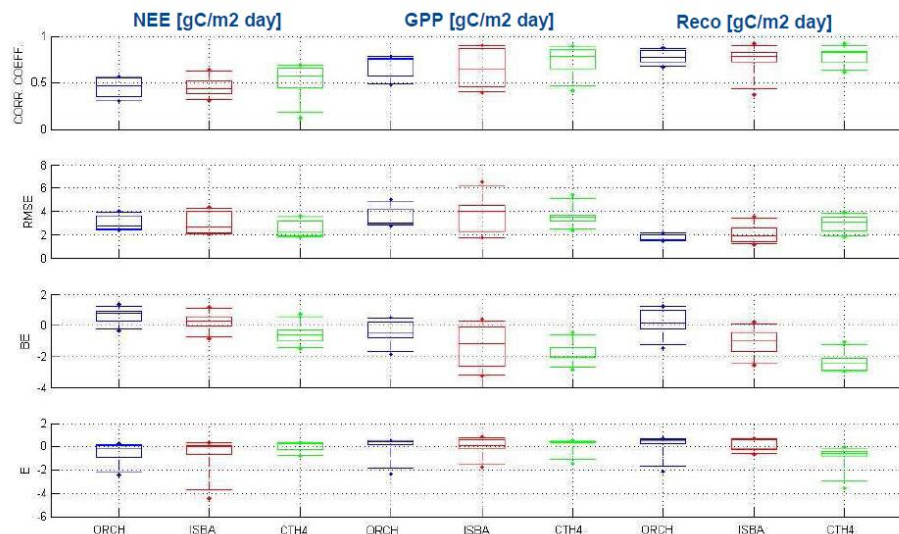


Forest

Grassland



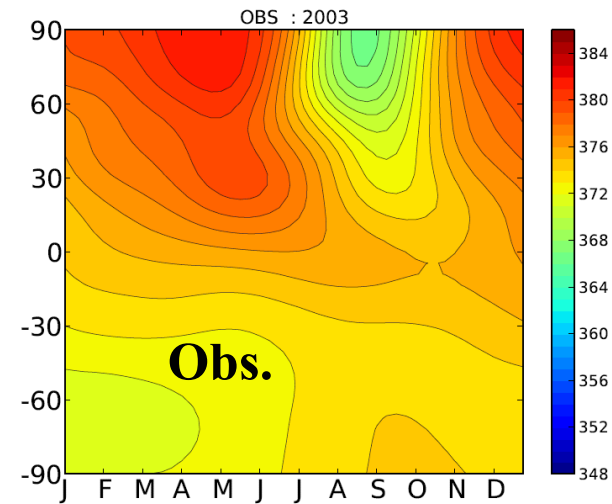
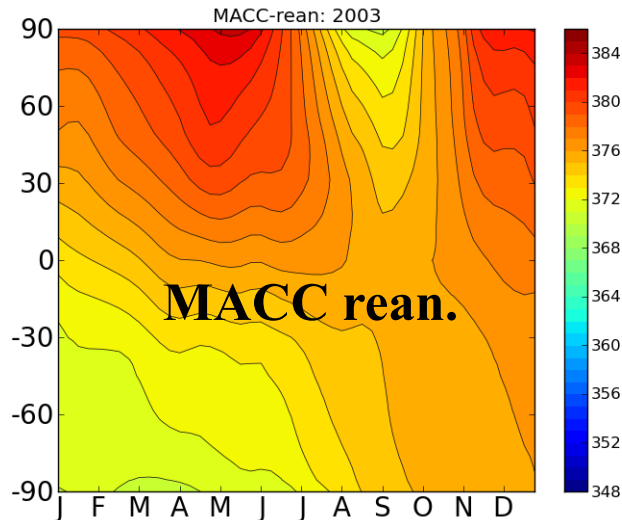
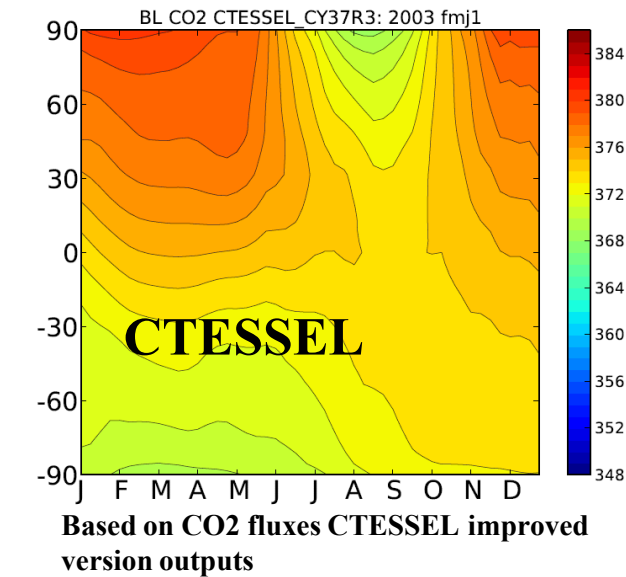
Cropland



CTESSEL in green  
ORCHIDEE in BLUE  
ISBA-Ags in red

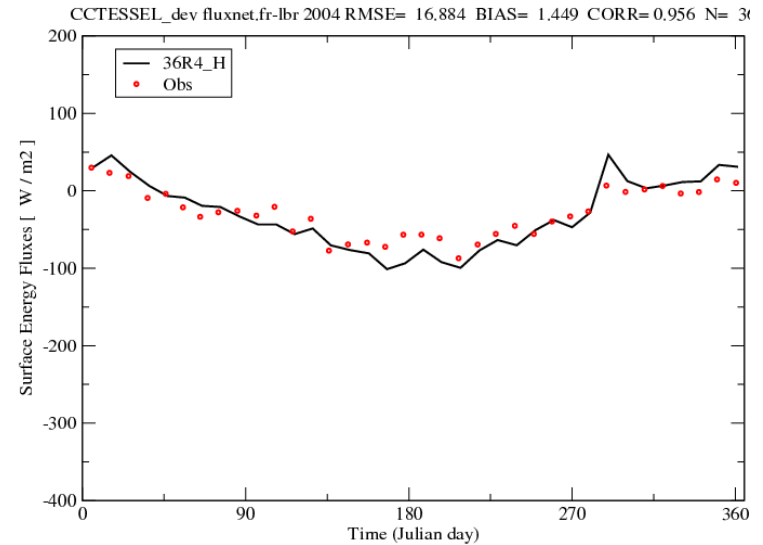
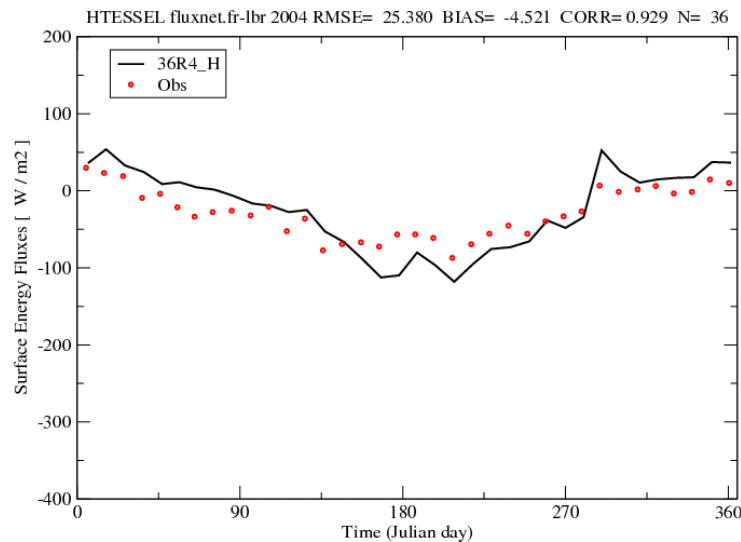
➔ With the 1-D offline simulation forced by ERA-Interim CTESSEL is outperforming ORCHIDEE and ISBA-Ags on most of the European stations for different biomes.

# Land Carbon improved feedback to the atmospheric CO<sub>2</sub>: Hovmoeller of CO<sub>2</sub> seasonal cycle - collaboration with MACC (A. Agusti-Panareda)

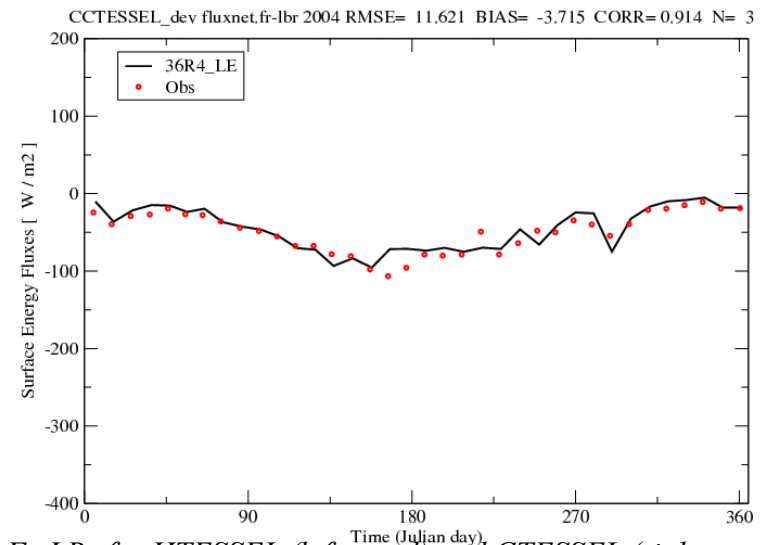
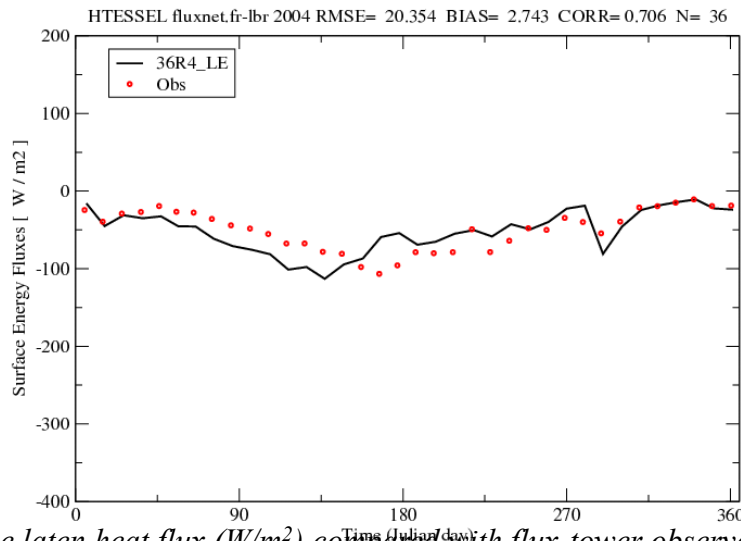


Based on processed marine BL observations  
(NOAA Globalview product)

# LE/H: CTESSEL vs HTESSEL (operational)



Surface sensible heat flux ( $\text{W/m}^2$ ) compared with flux-tower observations over Fr-LBr for HTESSEL (left panel) and CTESSEL (right panel)



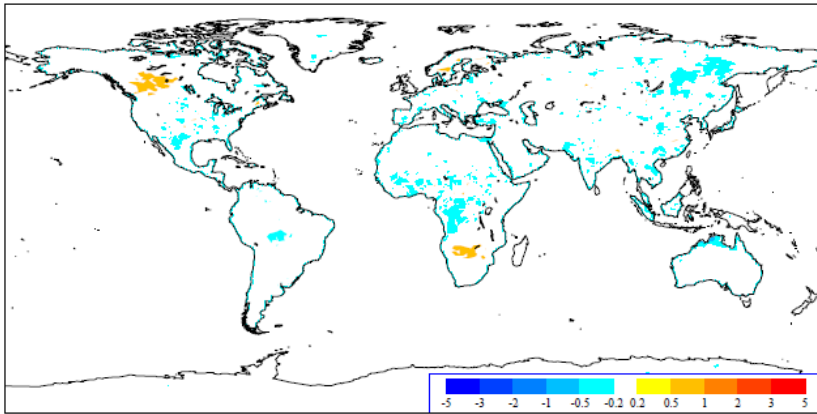
Surface latent heat flux ( $\text{W/m}^2$ ) compared with flux-tower observations over Fr-LBr for HTESSEL (left panel) and CTESSEL (right panel).

**CTESSEL improves the LE/H simulations (Jacobs vs Jarvis approach) therefore it has potential to improve weather forecasts...but**

# LE/H: Interaction with the atmosphere

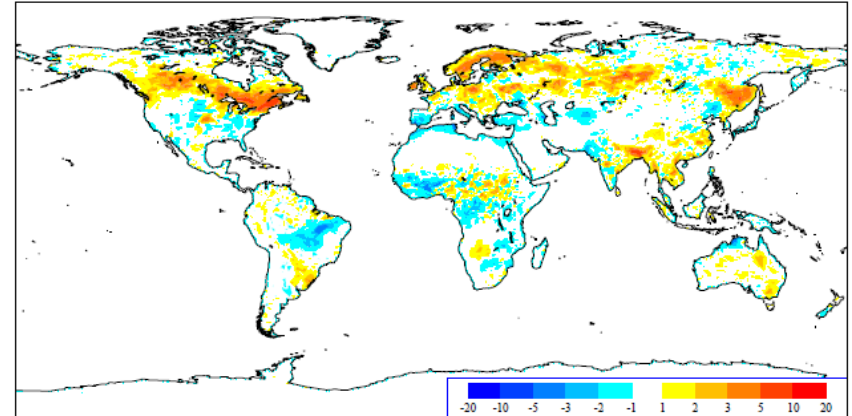
## 2m T Error differences from the CTL

T925 mean\_abs[CY37R1\_CTESSEL(ficd)+36-AN(ficd)]-mean\_abs[CY37R1(fhrr)+36-AN(fhrr)]



## 2m Rh Error differences from the CTL

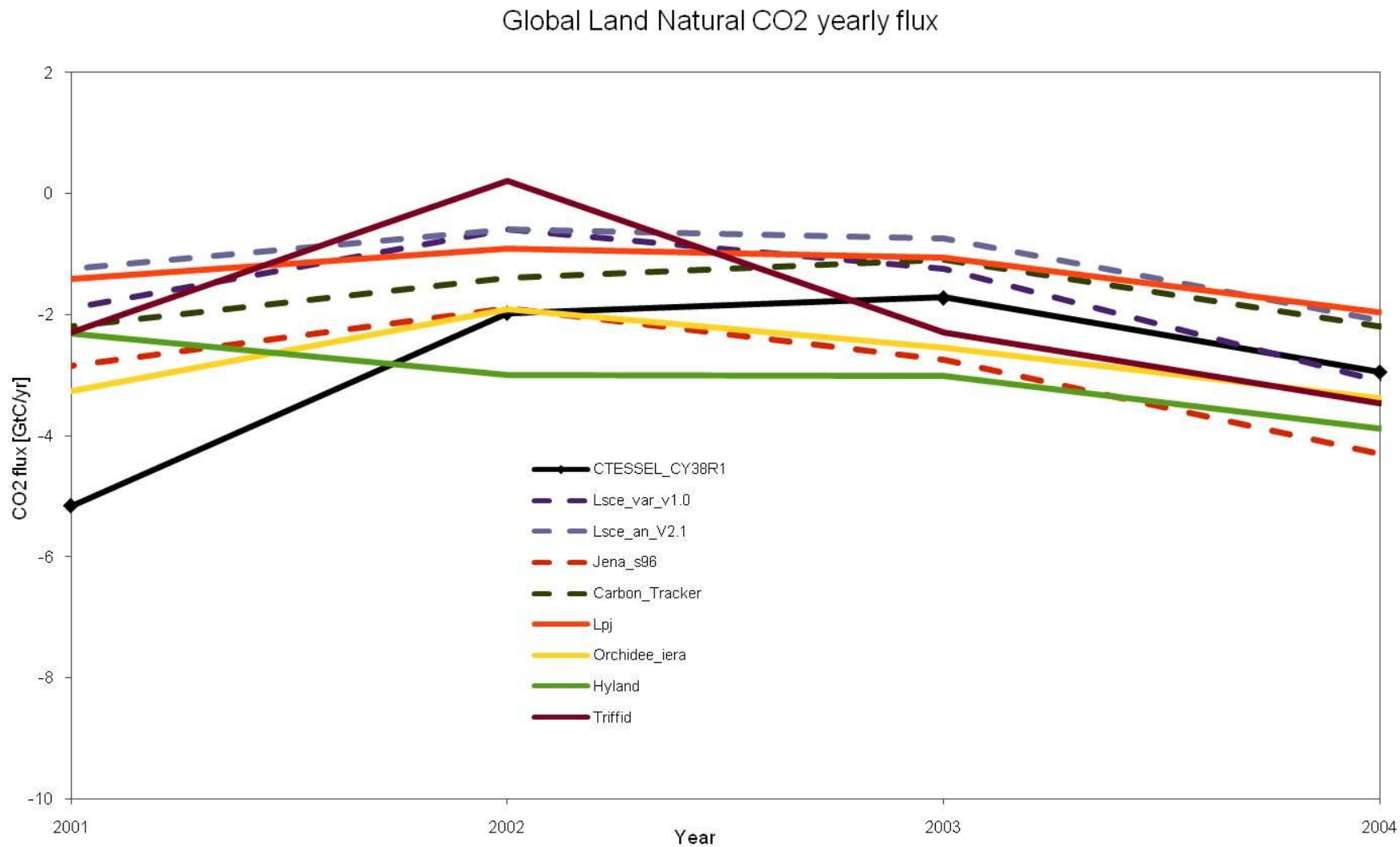
RH mean\_abs[CY37R1\_CTESSEL(ficd)+36-AN(ficd)]-mean\_abs[CY37R1(fhrr)+36-AN(fhrr)]



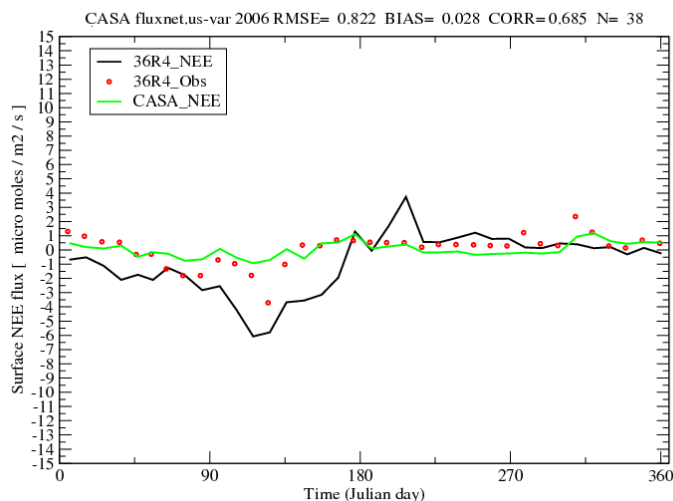
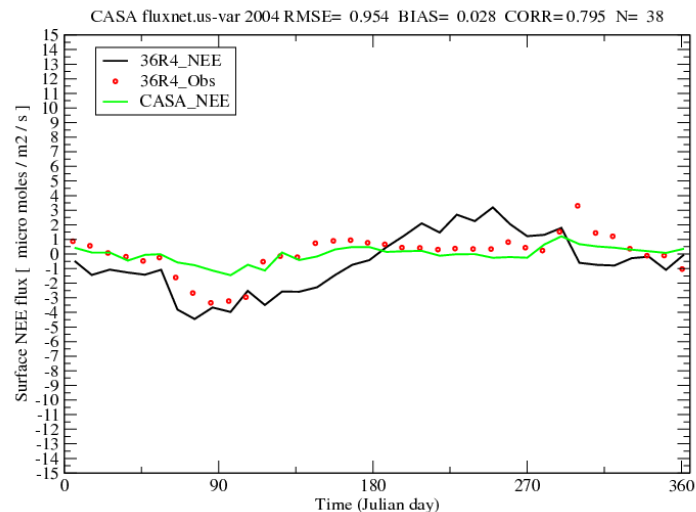
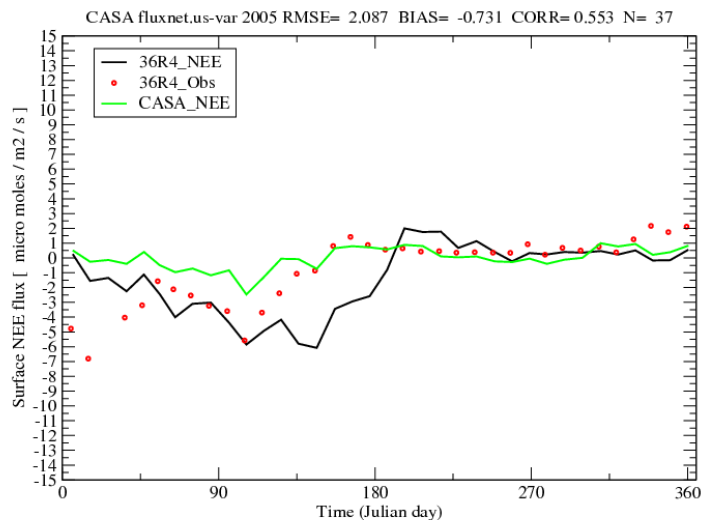
Having better LE/H heat flux from the surface (offline) does not always lead to a better atmospheric prediction → interaction with other processes and compensating errors?

A pragmatic solution is to keep separate the conductances calculation (CTESSEL has therefore neutral impact onto the LE/H)

# Global Natural land CO2 budget



# Current shortcomings: LAI variability?



Comparison of 3 different years show the current shortcoming of the use of LAI climatology => presence of large interannual variability? Harvest period not matched?

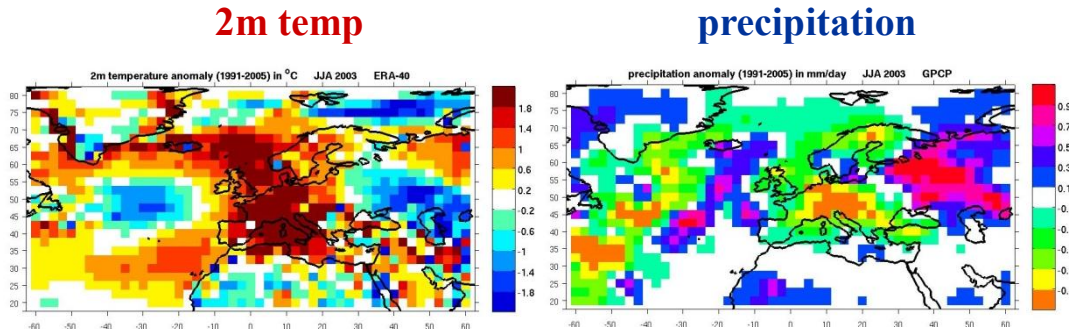
NEE (micro moles / m<sup>2</sup>/s) predicted over the site US-Var by **CTESSEL** (black line) and **CASA** (green-line)



# Impact of climate anomalies on CO2 flux: The summer 2003

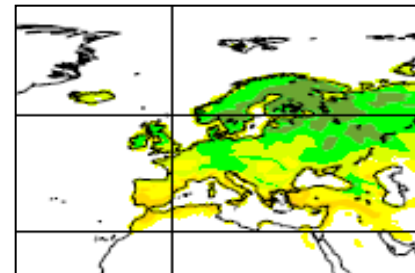
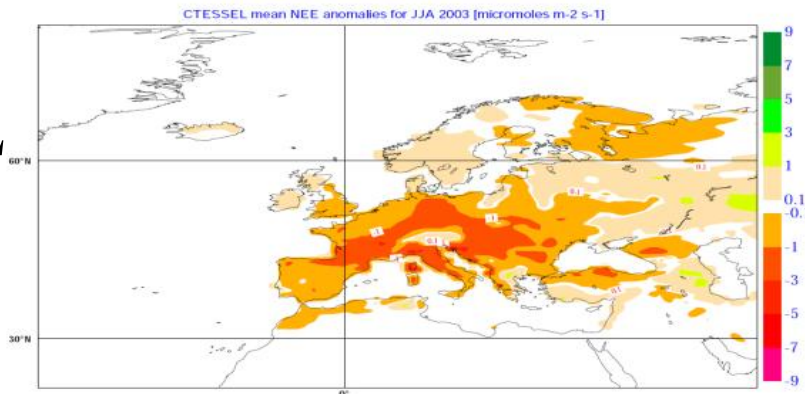
- Summer 2003 heat-wave/drought hitting western Europe. The effect on NEE was to turn land into a CO2 source due to vegetation stress conditions, consistently with findings of P. Ciais et al. (2005, Nature)

Observed  
anomaly



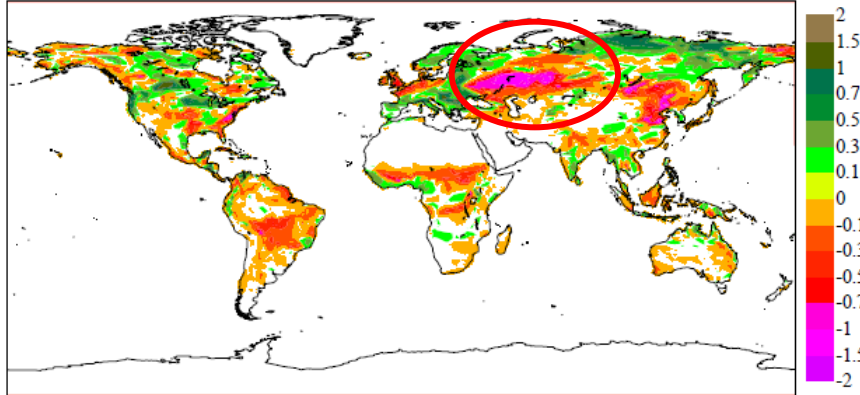
NEE

CTESSEL  
model  
anomaly

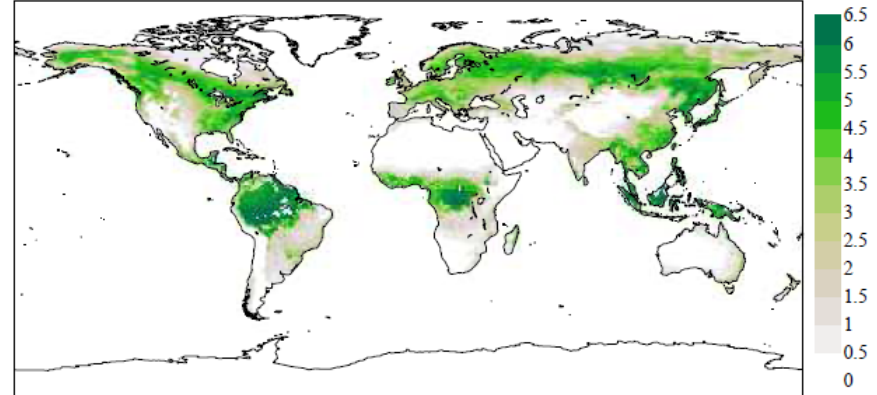


# LAI and CO2 flux inter-annual variability: The summer 2010 Russian case

CTESSEL Leaf Area Index anomaly from 1979-2010 mean [ $\text{m}^2/\text{m}^2$ ] for 201007

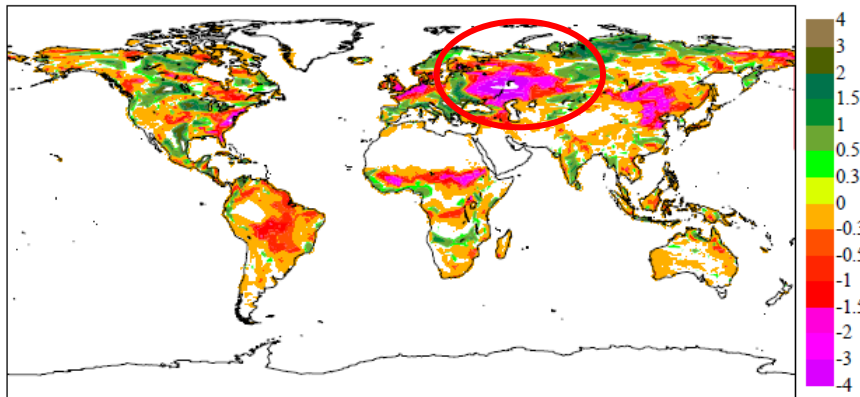


CTESSEL 1979-2010 monthly mean Leaf Area Index [ $\text{m}^2/\text{m}^2$ ] for 07

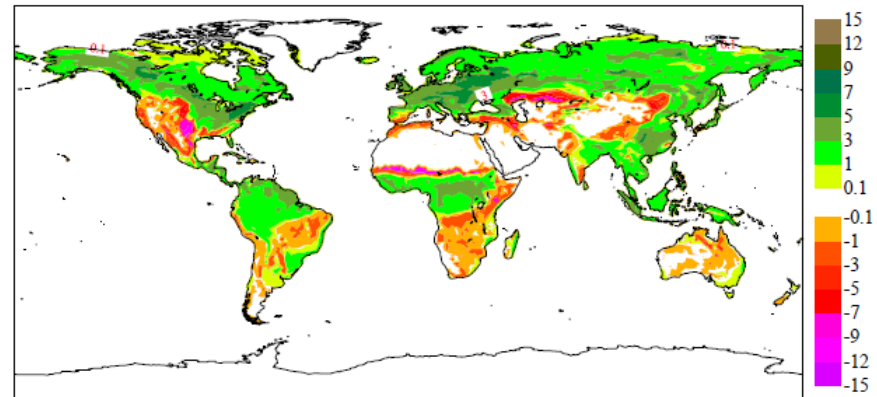


Preliminary results of CTESSEL with prognostic LAI detect anomalous years (here illustrating impact of the Russian heat-wave in July 2010) and have potential for vegetation growth monitoring

CTESSEL Net Ecosystem Exchange anomaly from 1979-2010 mean [ $\mu\text{mol}/\text{m}^2/\text{s}$ ] for 201007



CTESSEL 1979-2010 monthly mean NEE [ $\mu\text{mol}/\text{m}^2/\text{s}$ ] for 07





# Outline

- Introduction: model development in NWP & Climate
- Land surface evolution and current status
- Natural biosphere CO<sub>2</sub> uptake in NWP framework
- Ongoing land research
- Conclusions

# Land surface ongoing & future developments

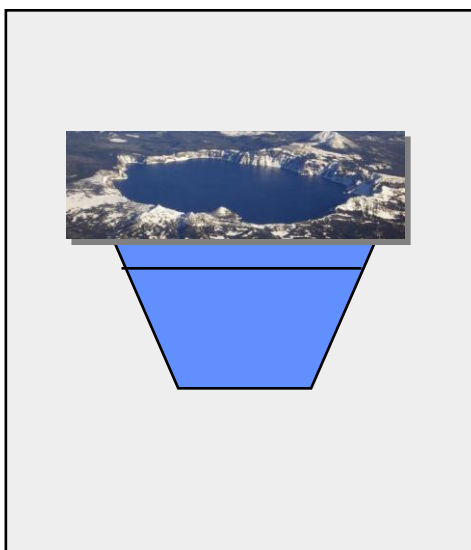
2012	2013-2015	2015-2020
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## ● FLake

Mironov et al (2010),  
Dutra et al. (2010),  
Balsamo et al. (2010)  
Balsamo et al. (2011)

Extra tile (9) to account  
for sub-grid lakes

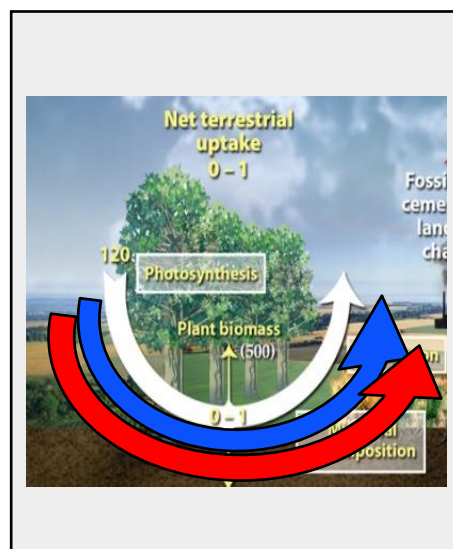
Lake Climatology used in  
S4



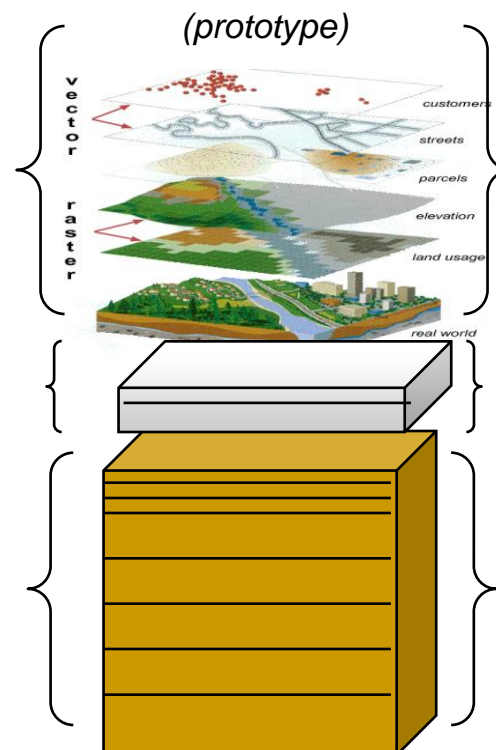
## ● H<sub>2</sub>O / E / CO<sub>2</sub>

Carbon-driven vegetation  
scheme at the surface  
(FP7 & GMES funded)

Boussetta et al. (2012 in  
prep.)

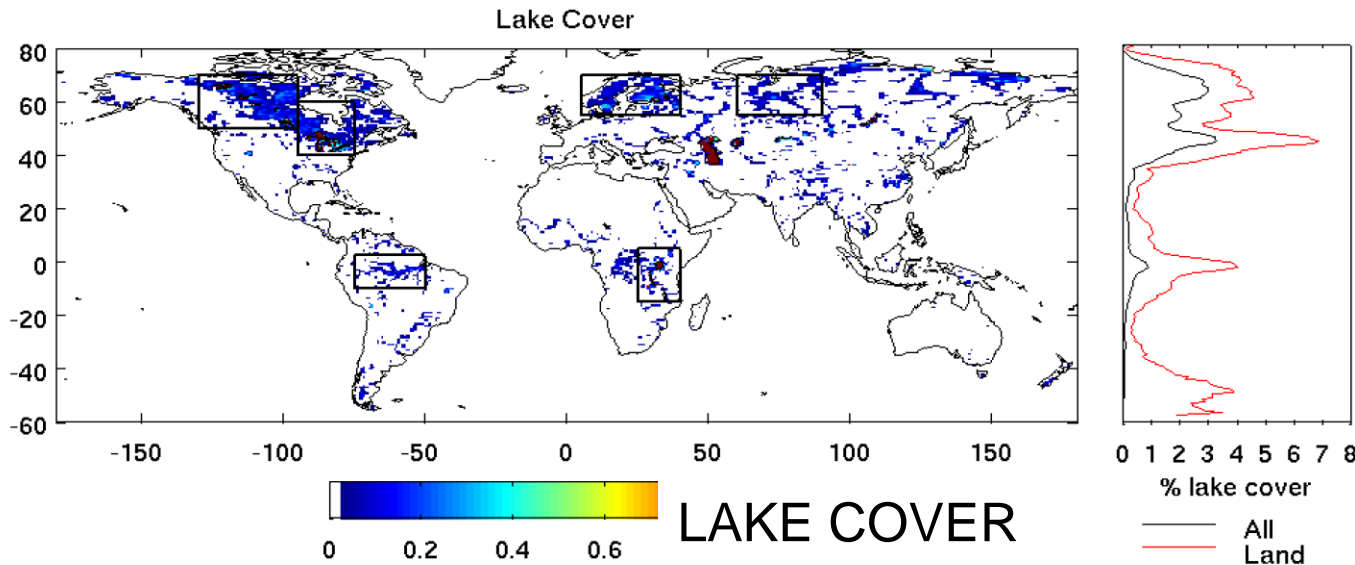


- Towards **Interactive Ecosystem** modelling  
to respond to several  
applications needs

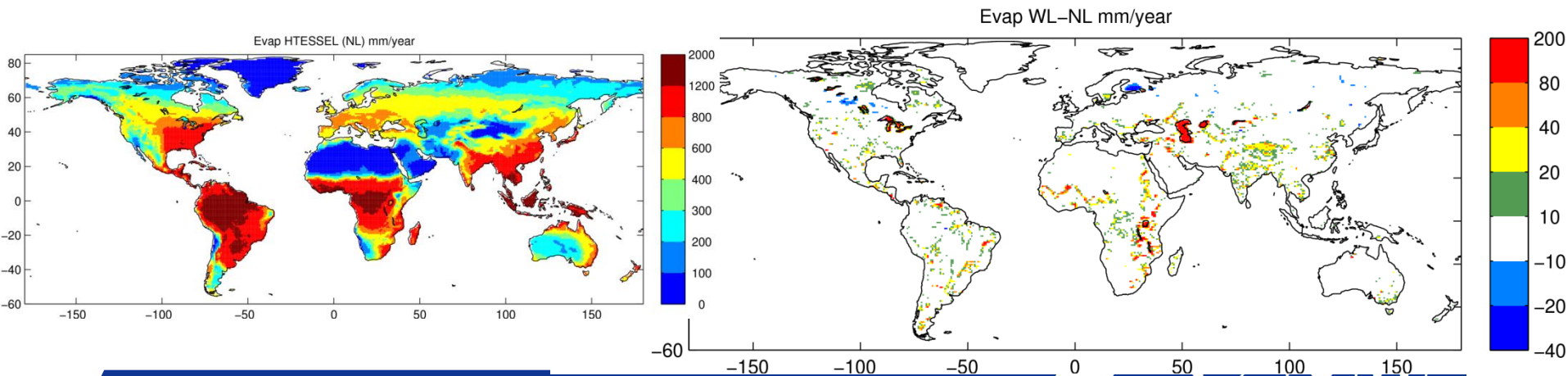


# Lake modelling

Dutra et al. (2009), Balsamo et al (2009), *Boreal Env. Res.*, and *TM608/609*

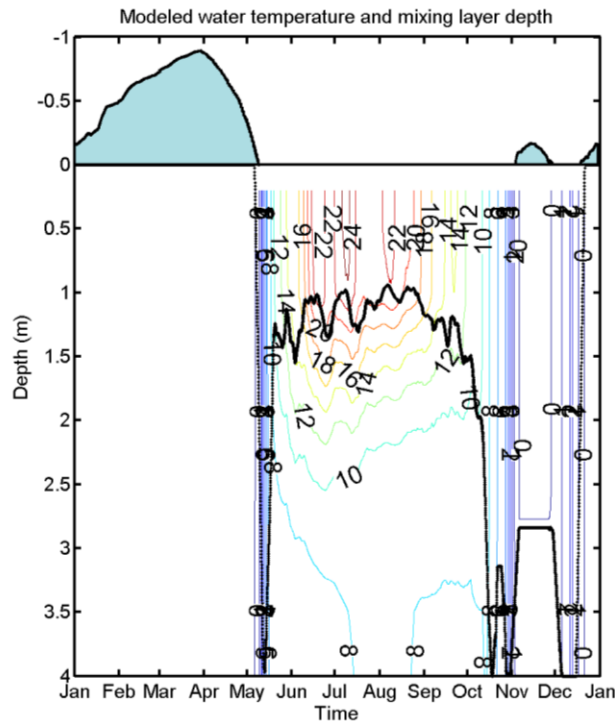
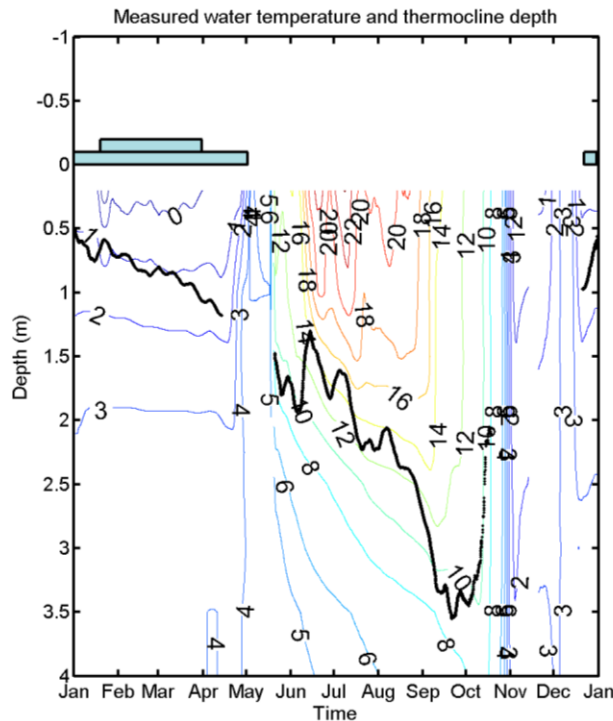


- FLAKE Lake model was tested in IFS CY35R3.
- Evaporation rates were increased in temperate climate
- L-band peak even stronger on lakes than SM!
- Crucial importance of lake depth



# FLake model compared to Lake observations

Andrea Manrique-Sunen, Annika Nordbo (U. Helsinki), Ivan Mammarella (U. Helsinki)



- Over a lake specialized site observations can be compared with FLake (Mironov et al. 2010) model output as provided by the LAKEHTESSEL model version (foreseen for 2012).

Courtesy of Annika Nordbo et al.  
(presented at EMS2011)

$T_b$  varying with lake  
temperature [ $f(T_{\text{skin}})$ ]

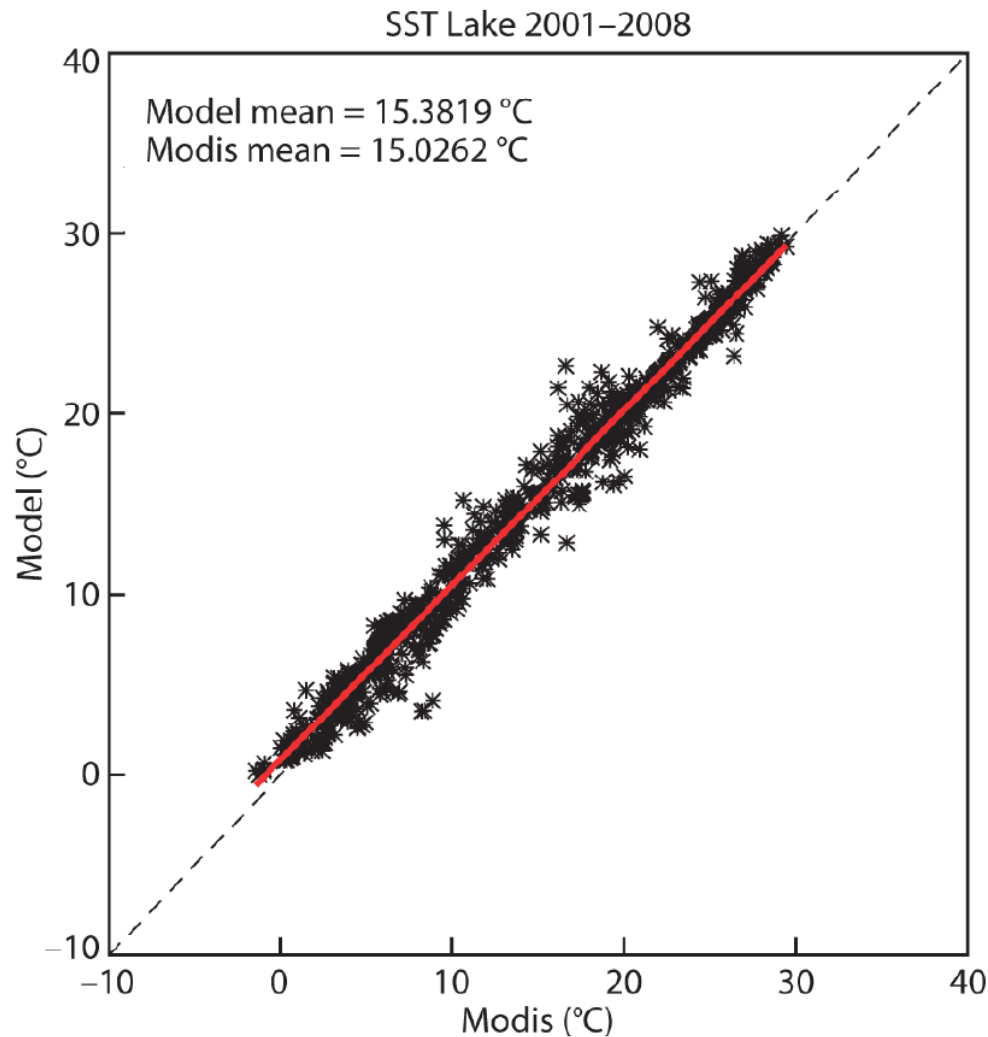
## Lake Valkea-Kotinen (FI)

- extinction coefficient  $3.0 \text{ m}^{-1}$
- depth 4 m, area  $0.041 \text{ km}^2$
- considering only lake

Nordbo et al. 2011

# FLake model in the IFS: global verification

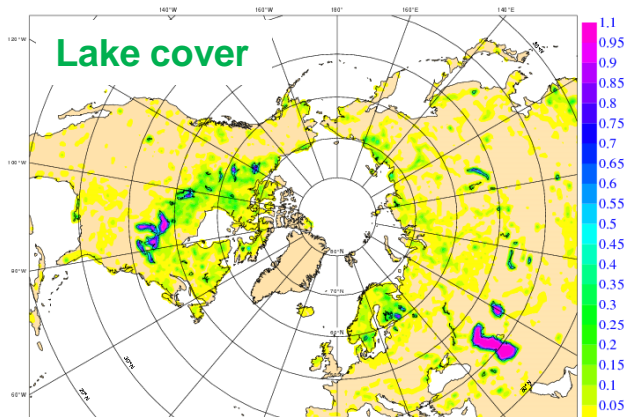
Balsamo et al (2011) *ECMWF TM 648*



- FLAKE Lake surface temperature is verified against the MODIS LST product (from GSFC/NASA)
- Good correlation  
 $R=0.98$
- Reduced bias  
 $\text{BIAS (Mod-Obs)} < 0.3 \text{ K}$

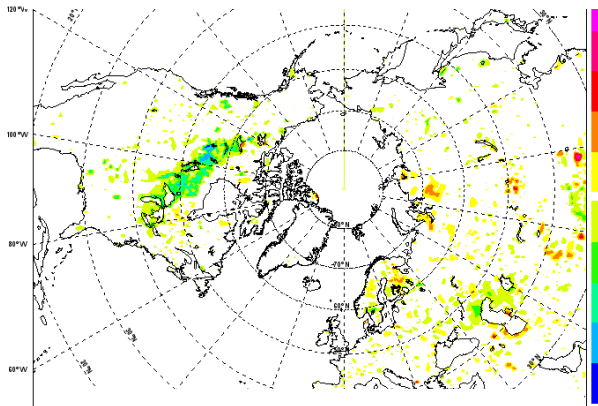
# FLake model in the IFS: Forecast impact

Balsamo et al (2012) *TELLUS-A lake special issue 2012 (accepted)*



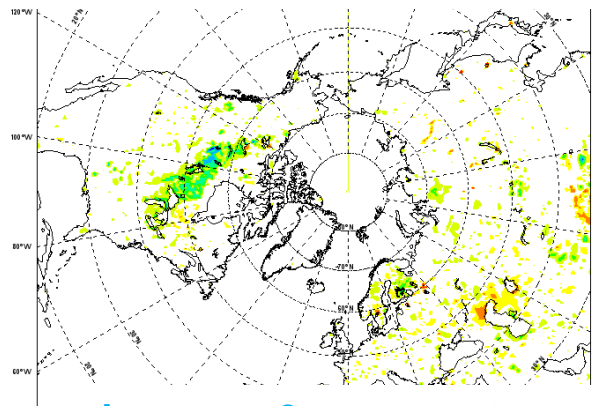
- Offline surface runs are used to prepare ICs for a new lake modelling component and permit the forecast assessment. Those fields are adopted by S4 as new lake clim.

Forecast sensitivity



Cooling 2m temperature  
Warming 2m temperature

Forecast impact

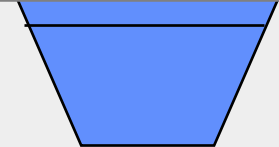


Improves 2m temperature  
Degrades 2m temperature

## ● FLake

Mironov et al (2010),  
Dutra et al. (2010),  
Balsamo et al. (2010)  
Balsamo et al. (2011)

Extra tile (9) to account  
for sub-grid lakes



ERA-Interim forced runs of the FLAKE model are used to generate a lake model climatology which serves as IC in forecasts experiments (Here it is shown spring sensitivity and error impact on temperature when activating the lake model).



# Conclusions and perspectives

- The current status of the operational land surface model and land data assimilation is summarized in the ECMWF Newsletter n. 127 [[link](#)].
- The land surface model development at ECMWF is moving towards Ecosystem modelling including Carbon Dioxide natural cycle as linked to Water and Energy.
- Several applications can benefit from the current land surface scheme (e.g. MACC/GAS, crop modelling, river modelling) and land surface benefits from a larger community of scientific users.
- Adding new modelling component extend the possibility of verification, monitoring and modelling, on the other hand the complexity of full-coupling needs care.
- Operational constraint and experience suggest that full-coupling between vegetation and atmosphere dynamics (via roughness) is subject to high sensitivity not fully understood.
- Similarly the photosynthesis-based algorithm is found to interact with low-level clouds and vertical diffusion and therefore carbon processes and evaporation processes have been made modular (Jarvis and Jacobs approaches co-existing)
- New developments in the land surface will focus on water bodies to improve the representation of natural microwave emission (C-band, L-band) for data assimilation

# Thank you for your attention I'll be happy to respond to questions

ECMWF Newsletter No. 127 – Spring 2011

## METEOROLOGY

### Evolution of land-surface processes in the IFS

GIANNI PAOLO BALSAAMO, SOUHAIB BOUSSETTA,  
BENJAMIN DUTRA, ANTON HILMERS,  
PIERO VITERBO, BART VAN DEN HUK

MANO UPGRADES have been implemented over the last few years in the soil hydrology, snow and vegetation components of the ECMWF land-surface parameterization. Compared to the scheme used in ERA-Interim and ERA-40 reanalyses, the current model has an improved match to soil moisture and snow field-site observations with a beneficial impact on the forecasts of surface energy and water fluxes and near-surface temperature and humidity. This is verified by conventional synoptic observations and by dedicated flux-tower sites for forecasts ranging from daily to seasonal. The gain in hydrological consistency is also of crucial importance for data assimilation of land-surface satellite observations in water sensitive channels. The scheme described here, currently used for daily medium-range forecasts, will be adopted by the new Seasonal Forecasting System and included in future reanalyses.

A brief description of the main hydrological components of the land-surface model with selected validation results will now be presented followed by an outlook for future research activities.

#### Development of the land-surface model

In recent years the land-surface modelling at ECMWF has been extensively revised. An improved soil hydrology (Bossett et al., 2009), a new snow scheme (Gut et al., 2010) and a multi-year satellite-based vegetation climatology (Bossett et al., 2011) have been included in the operational Integrated Forecasting System (IFS). These have had a positive impact on both the global hydrological water cycle and near-surface temperature compared to the TESSEL (Third ECMWF Scheme for Surface Exchanges over Land) scheme which was used in the ECMWF's ERA-40 and ERA-Interim reanalyses.

In particular the soil hydrology affected the quality of seasonal predictions during extreme events associated with soil moisture precipitation feedback as in the European summer heat wave in 2003 (Viterbo et al., 2011). The new scheme improved the thermal energy exchange at the surface with a substantial reduction of near-surface temperature errors in snow-dominated areas (i.e. northern territories of Eurasia and Canada).

More recently, the introduction of a monthly climatology for vegetation Leaf Area Index (LAI) to replace the fixed maximum LAI has shown a reduction of near-surface temperature errors in the tropical and mid-latitude areas, particularly evident in spring and summer. At the same time the base ground evaporation has been enhanced over deserts by adopting a lower stress threshold than for vegetation. This

is in agreement with experimental findings (e.g. Mahfouf & Noilhan, 1991) and results in a more realistic soil moisture for drylands.

The participation in international projects such as CLACE2 (Global Land-Atmosphere Coupling Experiment-2) and AMMA (African Monsoon Multidisciplinary Analysis), in which the ECMWF model was coupled with a realistic set of soil moisture fields, have improved the understanding of the mechanisms and areas of strong coupling between the land surface and the atmosphere.

#### The land-surface components

TESSEL as documented by van den Huk et al. (2000) and Viterbo & Beljaars (1995) is the backbone of the current operational land-surface scheme at ECMWF. It includes up to six land-surface tiles (bare ground, low and high vegetation, intercepted water, and shaded and exposed snow) which can co-exist under the same atmospheric grid-box. Recent revisions of the soil and snow hydrology as well as vegetation characteristics are illustrated in Figure 1.

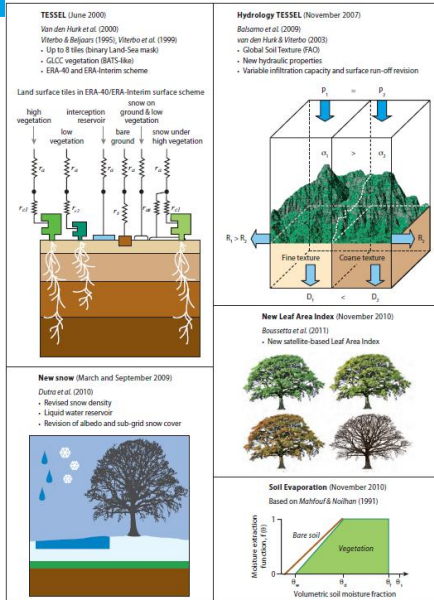
#### Soil hydrology

A revised soil hydrology in TESSEL was investigated by van den Huk & Viterbo (2005) for the Baltic basin. These model developments were a response to known weaknesses of the TESSEL hydrology, specifically the choice of a single global soil texture, which does not characterize different soil moisture regimes, and an infiltration-excess runoff scheme which prioritizes heavily dry surface runoff. Therefore, a revised formulation of the soil hydrological conductivity and diffusivity (spatially variable according to a global soil texture map) and surface runoff (based on the variable infiltration capacity approach) were introduced in IFS v2.5.1 in November 2007. Balsaamo et al. (2009) verified the impact of TESSEL from field site to global atmospheric coupled experiments and in data assimilation.

#### Snow hydrology

A fully revised snow scheme has been introduced in 2009 to improve the existing scheme based on Douville et al. (1995). The snow density formulation was changed and a liquid water storage in the snow-pack was introduced, which also allows the re-entrainment of rainfall. On the radiative side, the snow albedo and the snow cover fraction have been revised and the forest albedo in presence of snow has been obtained based on MODIS satellite estimates.

A detailed description of the new snow scheme and a verification from field site experiments to global climate simulations is presented in Dutra et al. (2010). The results showed an improved evolution of the simulated snow-pack with positive effects on the timing of runoff and streamflow water storage variation and a better match of the data to satellite products.



## METEOROLOGY

ECMWF Newsletter No. 127 – Spring 2011

### Extended Kalman Filter soil-moisture analysis in the IFS

PATRICIA DE ROSNAY, MATTHIAS DRUSCH,  
GIANNI PAOLO BALSAAMO,  
CLÉMENT ALBERG, LAÏS GAÛEN

A NEW soil moisture analysis scheme based on a point-wise Extended Kalman Filter (EKF) was implemented at ECMWF with cycle 364 of the Integrated Forecasting System (IFS) in November 2010. The EKF soil moisture analysis replaces the previous Optimum Interpolation (OI) scheme, which was used in operations from July 1999 (IFS cycle 21c2) to November 2010. In contrast with the previous system it uses 7-metre air temperature and relative humidity observations to analyse soil moisture. The computing cost of the EKF soil moisture analysis is significantly higher than that of the OI scheme. So, as part of the EKF soil moisture analysis implementation, a new surface analysis routine was implemented in September 2009 (cycle 353) to move the surface analysis out of the time critical path.

The main justifications for implementing the EKF soil moisture analysis are as follows:

- In contrast to the OI scheme, which uses fixed calibrated coefficients to describe the relationship between an observation and model soil moisture, the EKF soil moisture increments result from dynamical estimates that quantify accurately the physical relationship between an observation and soil moisture.
- The EKF scheme is flexible to cope with the commensurate model complexity. In particular, changes in the IFS and in the land-surface model (e.g. TESSEL hydrology, Third ECMWF Scheme for Surface Exchanges over Land) are accounted for in the analysis increments computation.
- The EKF soil moisture analysis makes it possible to use soil moisture data from satellites and to combine different sources of information (i.e. active and passive microwave satellite data, and conventional observations).
- It considers the observation and model errors during the analysis in a statistically optimal way and allows assimilation of observations at their correct observation times.

The implementation and evaluation of the EKF soil moisture analysis is described in this article, an overview is given of a set of one-year analysis experiments conducted to assess the performance of the EKF. These experiments led to the implementation of the EKF in November 2010 using coarser-level parameters to analyse soil moisture. The impact of ASCAT (Advanced Scatterometer) data assimilation is also briefly presented to investigate the possibility to combine conventional observations and satellite data for the soil moisture analysis.

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## METEOROLOGY

ECMWF Newsletter No. 127 – Spring 2011

### Tests of the EKF soil moisture analysis

#### Experimental set up

In preparation for implementing the EKF soil moisture analysis, three analysis experiments were conducted at T255 resolution over a one-year period (December 2008 to 30 November 2009).

- **OI experiment.** The OI soil moisture analysis uses the increments of the screen-level parameters analysis as input. It represents the operational soil moisture analysis configuration that was used in operations at ECMWF from July 1999 to November 2010.
- **EKF experiment.** This uses the dynamical EKF soil moisture analysis, in which the analysis of screen-level parameters is used as proxy information for soil moisture.
- **EKF+ASCAT experiment.** This was conducted for the same one-year period using the EKF in which the analysis of screen-level parameters is used together with the ASCAT soil moisture data.

In this EKF+ASCAT experiment, ASCAT soil moisture data is matched to the ECMWF E5 model soil moisture using a Cumulative Distribution Function (CDF) matching as described in Iqbal et al. (2008). A first demonstration of the impact of using a nudging scheme already been performed by Iqbal et al. (2008). They showed, however, that compared to the OI system, using scatterometer data slightly degraded the forecast score. They recommended using ASCAT data in an EKF analysis to account for observation errors and to combine ASCAT data with screen-level proxy information. This is investigated in the EKF+ASCAT experiment.

Note that:

- The OI and EKF experiments only differ in the method used for the soil moisture analysis. Observations used for the analysis are identical.
- The EKF and EKF+ASCAT experiments use the same EKF scheme, but satellite data is used in addition to conventional data in the EKF+ASCAT experiment.

One month of spin-up is considered for the first month of the experiment, so results presented here focus on the period January to November 2009.

#### Comparing the OI and EKF experiments

Figure 1 shows monthly accumulated soil moisture increments for the first month of soil for 2009 for the OI and EKF experiments, and their difference. Spatial patterns of soil moisture increments are quite similar for the OI and EKF schemes. For both the OI and the EKF the soil moisture increments are generally positive in most areas. However, negative increments are found in Argentina, Alaska and North East of America. These results mainly show that the EKF soil moisture analysis generally reduces the soil moisture analysis increments compared to the OI scheme.

Figure 2 shows the annual cycle of the global mean soil moisture increments for the OI and EKF experiments. It can be seen that the soil moisture increments of the OI scheme systematically add water to the soil. The global monthly mean value of the OI global mean increment is 5.5 mm, which represents a substantial and unrealistic contribution to the global water cycle.

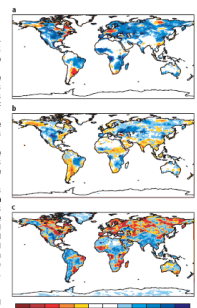


Figure 1 Monthly soil moisture increments (mm) within the top soil moisture root zone in 2009 produced by the OI scheme and the EKF scheme. (a) Difference between EKF and OI scheme.

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Recent advances on Soil moisture, Snow, and Vegetation components of the IFS modelling and data assimilation are summarized in newsletter articles available at:

<http://www.ecmwf.int/publications/newsletters/pdf/127.pdf>